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Integration and Penetration Opportunities of Alternative Energy, Fuels, and Technologies within Military Systems, Logistics, and Operations

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PREFACE

In the summer of 2008 a barrel of crude oil reached a record average price of $135/bbl (USD) driving the fuel cost to the consumer to a record national average of ~$3.91 per gallon. Furthermore, industry estimates have shown that approximately 70 percent of processed crude oil is currently imported to the United States for further processing and distribution as final goods. As the largest consumer of global fuel supplies, the United States has become increasingly dependent on crude oil imports from countries that do not always share in maintaining and developing U.S. national and international interests. As a result, the energy policy debate has begun to shift from one of strictly "supply and demand" to one of energy as a critical national security issue.

As one of the largest Government consumers of fuel, the Department of Defense (DoD) will play a vital role in addressing energy independence as it relates to national security. Estimates of the *Defense Science Board Report of 2008* and the *Army FY2007 Annual Energy Management Report* show that peacetime consumption of fuel by the military was 112.4 trillion British thermal units (TBtu), with approximately 67 percent being consumed by fixed infrastructure such as military facilities. The same reports also showed that during wartime operations DoD fuel consumption reached 206.4 TBtu, with 43 percent being consumed by ground (24 percent) and air vehicles (19 percent), and 22 percent being consumed by portable power generators.

It is against this backdrop that this IDA central research project (CRP) study was initiated to investigate the opportunities of alternative energies, fuels, and technologies (renewable energy) to meet and satisfy DoD military systems, logistics, and operational requirements. Specifically, this study focused on developing a process for assessing the technical maturity of current and emerging renewable energy sources, developing a common list of metrics that can be used to compare different alternative energy sources, fuels, and technologies, and finally, defining an integrated evaluation method that incorporates military customer requirements, DoD business goals, and DoD operational processes to effectively and accurately compare competing alternative energy sources, fuels, and technologies. This report describes the results of this study and is intended to serve as a starting point for follow-on analysis.

The Project Leader would like to thank Dr. Steve Warner (Division Director), Dr. Lisa C. Veitch, Dr. Joseph E. Hartka, and Ms. Jennifer J. Yopp of the System Evaluation Division (SED) for their comments, recommendations, and contributions to this report. In addition, the Project Leader would also like to thank Dr. Brent R. Fisher and Dr. Yevgeny Macheret from the Science and Technology Division (STD) for their early feedback and guidance in the development of the study proposal.

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EXECUTIVE SUMMARY

Recent global events in oil-rich regions (e.g., Iraq, Iran, Saudi Arabia, Georgia, and Venezuela), international natural disasters (e.g., Indonesian tsunami and China earthquake), and domestic natural disasters (e.g., Hurricane Katrina and Hurricane Ike) have amplified the sensitivity of domestic and international fuel markets to petroleum-based fuels and products. In all cases, the responses have been characterized by higher cost of fuels, instability in supply, supply chain/infrastructure damage, and reduced product quality. Also, widespread market globalization in emerging markets such as China and India have led to stresses in supply-and-demand market forces. While these effects have been widely reported in the domestic consumer and commercial markets, the ramifications on Department of Defense (DoD) military systems, operations, and logistics have not been well-understood.

In 2001 the Defense Science Board (DSB) task force report entitled *More Capable Warfighting Through Reduced Fuel Burden* identified a relationship between the amount of energy needed to support military operations and the overall net effectiveness of the deployed force, the total cost of producing a military capability, and force structure balance. In 2008, a second DSB task force examined the same topic in light of experience from Iraq and Afghanistan. They concurred with the 2001 observations and conclusions but added that, for scenarios involving contested lines of communications, risks to operational success increased and force protection demands further compromised overall operational effectiveness. The task force recommended that decisions made during the requirements development process be informed as to their consequences in terms of size of logistics organization, total costs, and effect on operational effectiveness based on the presence of the logistics organization inside the battlespace. The task force described this need as *quantifying* the consequences of options in the requirements process in terms of their operational effectiveness, cost, and force structure.

This CRP study describes the Technology Maturity Assessment Wheel (TMAW), Hierarchical Evaluation Metrics Tree (HEMT), and the Integrated Evaluation Method (IEM) that enable the quantitative comparison and evaluation of alternative energy sources, fuels, and technologies for commercial and DoD applications. Adequately assessing an alternative energy source, fuel, and/or technology as a viable acquisition option requires an assessment process that looks beyond just the cost per gallon or per kilowatt. It requires an understanding of common metrics and an integrated evaluation method that can systematically evaluate an energy source, fuel, or technology from feedstock source to full system integration and deployment.

Development of the TMAW, HEMT, and IEM was accomplished by using derivatives of well-known market and product requirements tools such as the Quality Function Deployment (QFD) House-of-Quality (HOQ), Six Sigma Define, Measure, Analyze, Integrate, and Control (DMAIC) techniques, Voice-of-the-Customer (VOC) techniques such as the Kano Survey, Critical-to-Quality (CTQ) trees, and Critical-to-Safety/Critical-to-Cost (CTS/CTC) analysis. Definition of Key Performance Parameters (KPPs) and Key System Attributes (KSAs) was also considered.

A fundamental question of the study was “how best to” apply the defined metrics and methods to military systems, logistics, and operations as it relates to selecting and evaluating alternative energy sources, fuels, and technologies. As an applied example, the IEM is used to examine alternative vehicle fuel technologies as motivated by the current Joint Light Tactical Vehicle (JLTV) Program and the Army Vehicle Modernization Program. These programs are currently under review and consideration by the DoD and Congress and present good opportunities for applying the proposed approach.

Before describing the TMAW, HEMT, and IEM, a survey of various alternative energy sources, fuels, and technologies is presented. To enable the analysis, renewable energy technologies are categorized into fixed infrastructure, vehicles, and portable power. The fixed infrastructure analysis looks at renewable energy source examples such as solar, wind, geothermal, and biomass energy production versus current coal and natural gas facilities. The vehicle fuel analysis looks at various alternative liquid fuels such as biodiesel (e.g., cellulosic- or algae-based) and vehicle drive technologies (e.g., hybrid-electric) along with other fuels listed as alternative fuels by the Energy Policy Acts (EPActs) of 1992/2005. Fuel cells and battery technologies used in portable power solutions are also considered.

The competitive landscape for alternative energy, fuel, and technology companies is of significant importance in ensuring continued adequate supplies of the renewable energy source along with constant technical innovation. The viability, reliability, and quality of any renewable energy supply chain is in many ways directly tied to the number of companies that are responsible for producing and investing in the alternative energy, fuel, and/or technology. From the DoD perspective, the viability of integrating an alternative energy, fuel, and/or technology into military systems, logistics, and operations is also directly tied to ongoing research and development (R&D) efforts at primary DoD R&D centers. After discussion of the developed metrics, methods, and the JLTV applied example, this report provides a cursory look at the number of renewable energy private businesses and discusses some of the more visible DoD R&D efforts that can help to realize the result of the metrics and methods approach of this study.

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I. BACKGROUND

Recent global events in oil-rich regions (e.g., Iraq, Iran, Saudi Arabia, Georgia and Venezuela), international natural disasters (e.g., Indonesian tsunami and China earthquake), and domestic natural disasters (e.g., Hurricane Katrina and Hurricane Ike) have amplified the sensitivity of domestic and international fuel markets to petroleum-based fuels and products. In all cases, the responses have been characterized by higher cost of fuels, instability in supply, supply chain/infrastructure damage, and reduced product quality. Also, widespread market globalization in emerging markets such as China and India have led to stresses in supply-and-demand market forces. While these effects have been widely reported in the domestic consumer and commercial markets, the ramifications on Department of Defense (DoD) military systems, operations, and logistics have not been well-understood.

In 2001 the Defense Science Board (DSB) task force report entitled *More Capable Warfighting Through Reduced Fuel Burden* identified a relationship between the amount of energy needed to support military operations and the overall net effectiveness of the deployed force, the total cost of producing a military capability, and force structure balance. The concept is that high-energy demand by operational forces detracts from overall effectiveness by increasing the size of the logistics footprint needed to support the operation, skewing the overall force structure balance toward support and increasing overall costs. In 2008, a second DSB task force examined the same topic in light of experience from Iraq and Afghanistan. They concurred with the 2001 observations and conclusions but added that, for scenarios involving contested lines of communications, risks to operational success increased and force protection demands further compromised overall operational effectiveness. The task force noted that decisions made during the requirements development process affected demands for fuel to be delivered to operational forces, which, in turn, created the need for a logistics organization. This logistics organization added to the cost of fielding an operational capability, and the presence of this logistics organization in the battlespace created a risk to operational forces and diluted operational effectiveness by requiring diversion of combat assets to perform force protection duties. The task force recommended that decisions made during the requirements development process be informed as to their consequences in terms of size of logistics organization, total costs, and effect on operational effectiveness based on the presence of the logistics organization inside the battlespace. The task force described this need as quantifying the consequences of options in the requirements process in terms of their operational effectiveness, cost, and force structure.

A. FOCUS

A breadth of alternative (renewable) energy, fuels, and technologies exists in various phases of commercial and research and development (R&D) availability. The most common include solar technology, wind power, liquid fuels (ethanol), fuel cells, biomass fuels (biodiesel), hybrid vehicles, portable power (battery) technologies, thermal energy sources, and nuclear power. Technologies such as nano-technology sources, laser-based energy, and radio frequency (RF) energy transmission have also been considered in academic research and Government laboratory environments. While these alternative energy sources, fuels, and technologies have begun to emerge in the commercial sector, the DoD has also initiated efforts to integrate, test, and evaluate such sources and technologies in military systems, operations, and logistics. A few examples include military aviation biofuel, U.S. Army's diesel-electric hybrid Aggressor, BAE Systems Ground Combat hybrid vehicle, Tank Automotive Research, Development, and Engineering Center's (TARDEC's) Solar Soldier vest, and Mechanical Technology, Inc.'s (MTI's) micro-fuel cell.[1]

Unfortunately, these efforts are characterized by disjointed activity that does not provide for a well-structured and well-understood method to adequately assess the effectiveness of the new technology. Common metrics, methods, and evaluation techniques for such a diverse set of alternative energies, fuels, and technologies have not been proposed. Furthermore technology maturity level and risk assessments have not been adequately studied or documented prior to integration into DoD efforts. Finally, commercial investment, availability of delivery support infrastructure, and the competitive (foreign and domestic) landscape for such technologies must be better understood in order to more accurately cost the research, development, testing, and

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[1] Source: http://earth2tech.com/2007/08/28/7-ways-the-military-is-using-eco-tech.

evaluation (RDT&E) of DoD efforts in migrating to these new alternative energy sources, fuels, and technologies.

B. OBJECTIVE

The primary objective of this study was to develop a common list of metrics and define a well-structured method that can be used by DoD programs to adequately assess the overall effectiveness of integrating and deploying alternative energy sources, fuels, and technologies in military systems, logistics, and operations. Beyond the technical difficulties that arise in migrating to these new energy and fuel sources, a well-defined evaluation method with common metrics can greatly aid in improving the accuracy of cost-benefit models. Furthermore, given the significant differences in the base technologies for some of the new energy and fuel sources, having well-understood metrics can aid in performing direct intra- and inter-technology comparisons.

A secondary objective of this study was to perform a broad technology survey and to conduct technology maturity-level assessments. Where possible, the technology maturity-level assessments used existing DoD-approved guidelines for assessing alternative energy and fuel technology maturity levels. Where not possible, it was necessary to propose new maturity-level assessment techniques to address the uniqueness of the new technology.

A final objective of this study was to develop and document an understanding of the commercial investment (market) in each of the alternative energy, fuel, and technology sources considered. This would assess private sector investment and academic activity, look at supply chain cost and risk reduction, and availability of delivery support infrastructure. Finally, an understanding of the competitive landscape of the developers, suppliers, and providers of these new technologies is included as a guide for future use.

C. APPROACH AND SCOPE

The study's initial approach was to conduct a broad survey of existing literature, reports, and Government agency [(DoD and Department of Energy (DoE)] published information on existing and emerging energy, fuels, and technologies classified as "alternative" per the Energy Policy Act of 1992 (EPAct), the Energy Policy Act of 2005 (EPAct 2005), and the Energy Independence and Security Act of 2007 (EISA). While a diversity of new alternative sources of energy, fuels, and associated technologies have emerged since the publishing date of EPAct, particularly in vehicle alternative fuels, the study used the list in EPAct as a starting point (baseline) for the study. This afforded the study a focused view on what is currently classified as alternative energy, fuels, and technologies per Federal Government policy.

This study presents a quantitative method, called the Integrated Evaluation Method (IEM), for comparing competing alternative energy sources, fuels, and/or technologies as potential acquisition options. Development of the IEM was accomplished by using derivatives of well-known market and product requirements tools such as the Quality Function Deployment (QFD) House-of-Quality (HOQ), Six Sigma Define, Measure, Analyze, Integrate, and Control (DMAIC) techniques, Voice-of-the-Customer (VOC) techniques such as the Kano Survey, Critical-to-Quality (CTQ) trees, and Critical-to-Safety/Critical-to-Cost (CTS/CTC) analysis. Definition of Key Performance Parameters (KPPs) and Key System Attributes (KSAs) was also considered.

The scope of this study was to develop the IEM for comparing and assessing alternative energy sources, fuels, and technologies. While it is important to present the motivation for considering these energy sources, fuels, and technologies in current and future military systems, several well-documented studies such as the *Report of the Defense Science Board Task Force on DoD Energy Strategy* (AT&L - February 2008) and the Center for Naval Analyses (CNA Corporation) *National Security and Threat of Climate Change Study Report* (2007) sufficiently present the motivation and is thus not repeated, but rather referenced, in this study.

D. APPLICATION OF RESULTS TO MILITARY SYSTEMS, LOGISTICS, AND OPERATIONS

A fundamental question of the study was how best to apply the defined IEM to military systems, logistics, and operations as it relates to selecting and evaluating alternative energy sources, fuels, and technologies. While this is a very broad and complex question, the Joint Capabilities Integration and Development System (JCIDS) Manual[2] may serve as valuable guidance and is considered in this study. Its applicability comes in assessing the defined metrics as potential KPPs or KSAs.

[2] Joint Capabilities Integration and Development System (JCIDS) Manual, 31 July 2009.

E. STUDY SUMMARY

This study presents a “systems-based” technology maturity assessment process titled, “Technology Maturity Assessment Wheel (TMAW)”; a list of metrics, titled “Hierarchical Evaluation Metrics Tree (HEMT)”; and a technical/business process method, titled “Integrated Evaluation Method (IEM)”; to evaluate alternative energy sources, fuels, and technologies for use in military systems, logistics, and operations. It is acknowledged that providing a complete list of metrics and method for all military systems, logistics, and operations requirements is extremely challenging and may not be entirely captured in any single method or list of metrics. However, it is the goal of this study to provide a starting point and a generic template that can be easily modified and adapted to the diversity of military ground, air, and maritime requirements.

As an applied example, the IEM is used to examine alternative vehicle fuel technologies as motivated by the current Joint Light Tactical Vehicle (JLTV) Program and the Army Vehicle Modernization Program. These programs are currently under review and consideration by the DoD and Congress and present good opportunities for applying the proposed approach. Before presenting the evaluation techniques of this study and the subsequent example, Chapter II provides a broad technical survey of existing and emerging alternative energy sources, fuels, and technologies.

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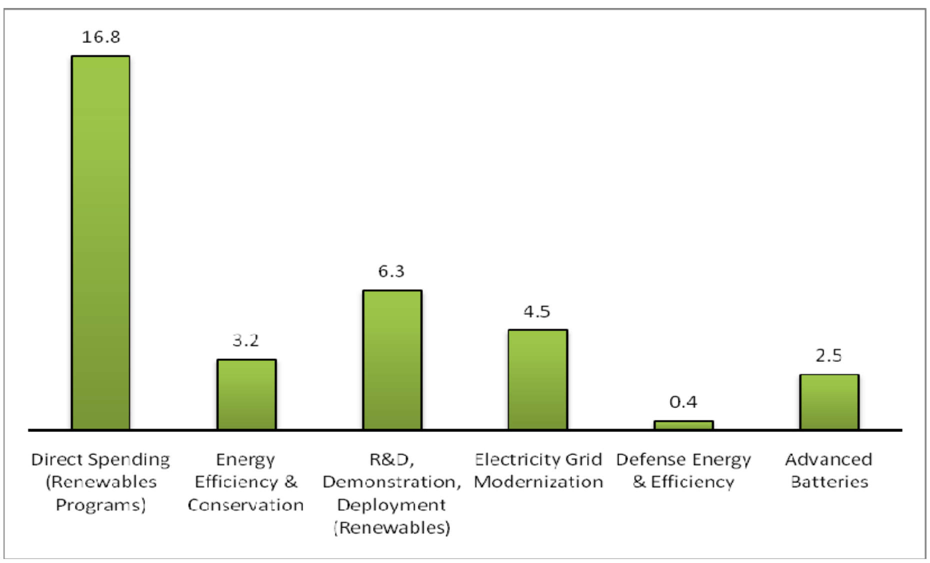
II. ALTERNATIVE ENERGY, FUELS, AND TECHNOLOGIES

A. EXISTING AND EMERGING ALTERNATIVE ENERGY, FUELS, AND TECHNOLOGIES SURVEY

The type of existing and emerging alternative (renewable) energy sources, fuels, and technologies continue to evolve each year as more and more public and private investment is made in R&D and production of supporting technology. The American Recovery and Rehabilitation Act of 2009 (ARRA 2009) signed into law on 17 February 2009 introduced significant Government investment in alternative energy R&D, energy efficiency, and other energy-related initiatives. A total of $37.5 billion (USD) was included in the ARRA 2009 in the form of investment and tax credits. Figure 1 shows a sample list of energy-related allocations made by provisions contained within the ARRA 2009.



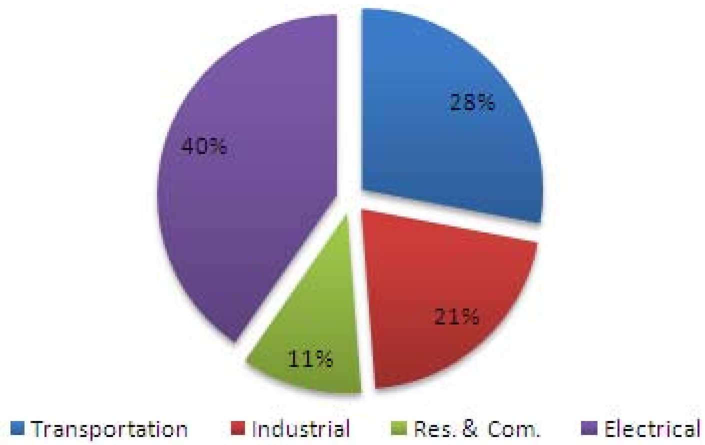
Source: Summary of Energy-Related Provisions—American Recovery and Rehabilitation Act 2009, Dorsey & Whitney LLP

Figure 1. ARRA 2009 Sampling of Energy-Related Allocations

In addition to the ARRA 2009 Government investment, private investment in alternative energy sources, fuels, and technologies also continues to increase as adoption of these technologies increases. Investments are being made in R&D, infrastructure improvements, distribution chains, and production. Investments are also being made in all primary fields of energy consumption including fixed infrastructure technologies, alternative vehicle fuels and hybrid technologies, and portable power/battery technologies.

1. Fixed Infrastructure Technologies

Fixed infrastructure such as residential housing, commercial centers, industrial parks, and military installations continue to represent the largest consumer of non-renewable energy sources derived from fossil-fuel-based feedstocks. When combined, homes, businesses, manufacturing facilities, and military bases far exceed the consumption of the transportation industry. According to the Energy Information Administration (*Annual Energy Outlook Early Release Review 2009*), the combined energy consumption for residential, commercial, and industrial sectors in 2007 was ~31.4 quadrillion British thermal units (Btus). This is compared to ~28 quadrillion Btus for the transportation sector. At ~40 quadrillion Btus, the electricity generation sector consumes the largest amount of energy in the United States. Figure 2 shows energy consumption by sector in 2008 as a percentage of total consumption.



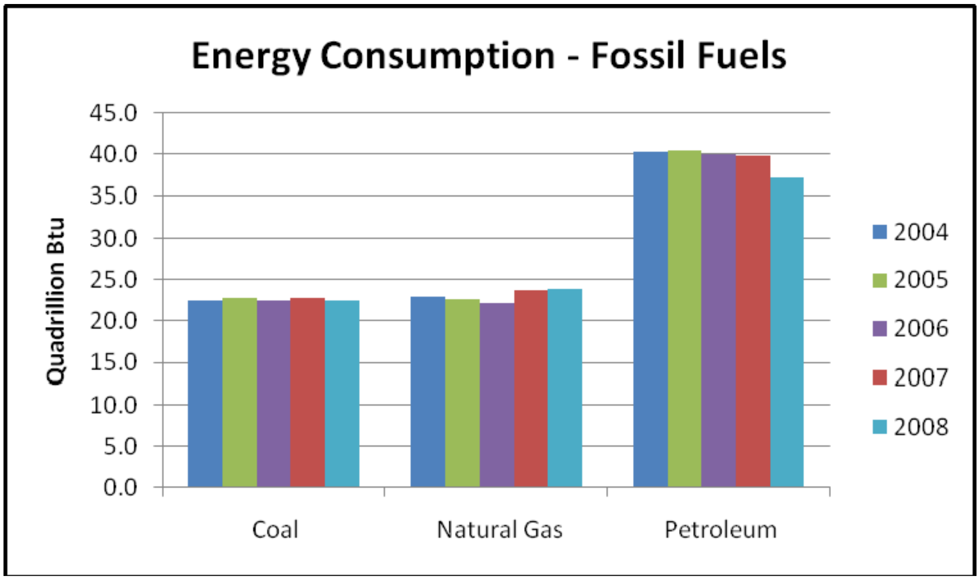
Source: Energy Information Administration, Annual Energy Outlook 2009—Early Release Review, 2009

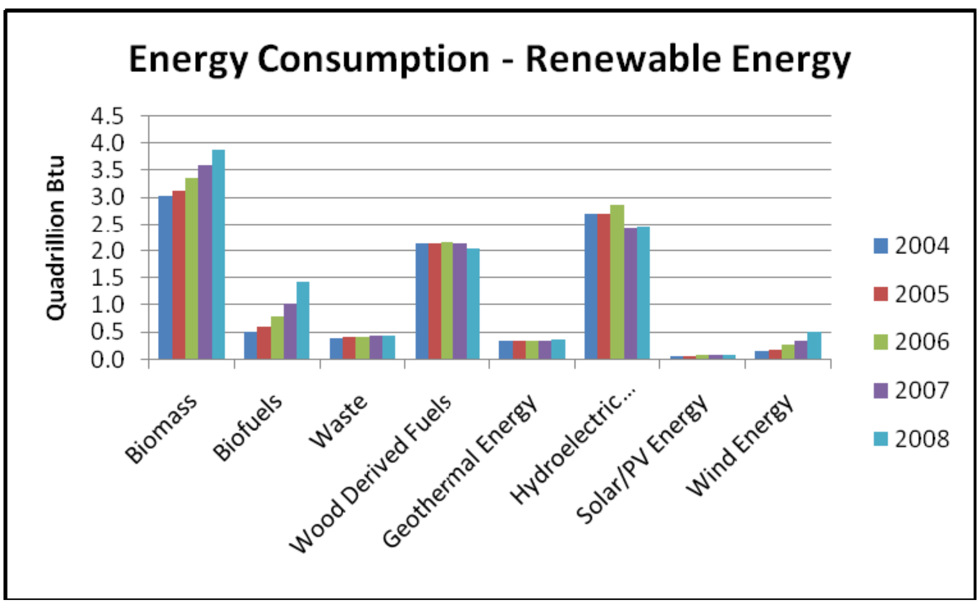
Figure 2. Percent of Energy Consumption by Section—2008

With the total of fixed infrastructure energy consumption representing 72 percent of the total consumption in the United States, this area has been the focus of very active renewable energy and energy efficiency initiatives as is shown by the emphasis of the ARRA2009 allocations. Further motivation has been the current reliance on coal, oil (mostly through foreign imports), and natural gas to meet more than 85 percent of the fuel used to meet energy supply requirements.[3]

To address the national security and climate change issues presented by having such a high dependence on fossil fuels (e.g., coal, oil, and natural gas) to generate fixed infrastructure energy supply requirements, several alternative energy sources exist and have continued to evolve over many years. They include renewable sources such as biomass, geothermal, hydroelectric, solar/photovoltaic, and wind. Nuclear power has also been used and continues to be used to meet growing fixed infrastructure energy requirements. Figure 3 shows the energy consumption by fossil-fuel-based and renewable energy supplies for 2004-2008.

[3] Energy Information Administration, *Annual Energy Outlook 2009*, January 2009.





Source: Energy Information Administration Report, May 2008

Figure 3. U.S. Energy Consumption by Source

It is interesting to note the rather steady increase in supply coming from biomass, biofuels, and wind energy. Solar energy sources also continue to increase, but the technical challenges in efficiently converting solar energy to electrical energy makes its increase less evident. Of particular interest in this study is the 10:1 difference in the energy consumption vertical scale of the two basic source types shown in Figure 3, fossil fuels and renewable energy, respectively. This difference helps to quantify the significant reliance upon fossil fuels to meet current U.S. energy supply requirements.

As stated earlier, it is not the purpose of this study to deeply examine the technical challenges and details of all existing and emerging alternative energy sources, fuels, and technologies, but merely to list them here as opportunities for further study and research and for the development of the TMAW, HEMT, and IEM of Chapters III and IV.

2. Vehicle Fuels, Hybrid, and Alternative Technologies

When considering the individual energy consuming sectors of Figure 2, the transportation industry represents the second largest energy-consuming sector, accounting for approximately 28 percent of all energy consumed in the United States (behind electrical power generation at 40 percent). The Energy Information Administration (EIA) estimates that by 2030, transportation energy consumption will reach 31.9 quadrillion Btus, which is an estimated 3.9 quadrillion Btus above 2007 levels.[4] Leading consuming industries include automotive (personal/business), trucking, air transportation, mass transit, and maritime shipping.

Petroleum-based liquid fuels continue to be the highest source of supply used to meet the required transportation consumption demands. In 2008, motor gasoline consumption reached 9.29 million barrels per day.[5] As shown in Figure 4, 95 percent of the sources used to meet the transportation energy consumption demand were derived from petroleum-based supplies. This is compared to only 2 percent and 3 percent for natural gas and renewables, respectively.

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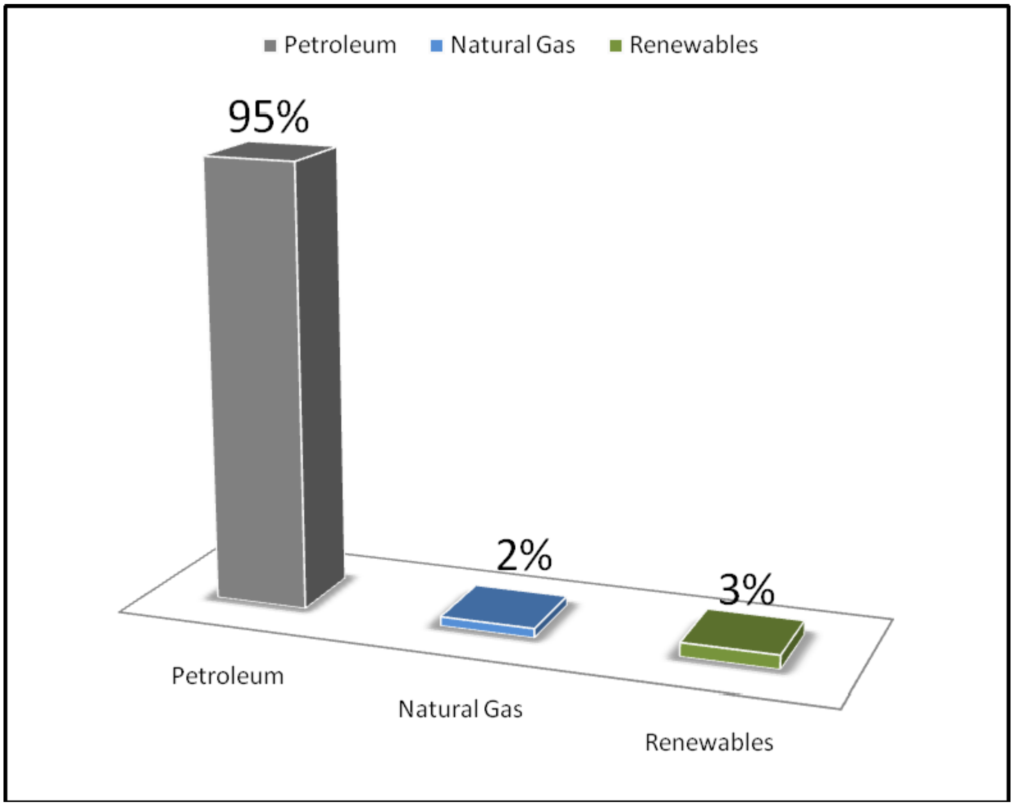
[4] Energy Information Administration, *Annual Energy Outlook 2009*, January 2009.

[5] Energy Information Administration, *Annual Energy Review 2008*, Report No. DOE/EIA-0384(2008), 26 June 2009.



Source: EIA Annual Energy Outlook 2009-Early Release Review, 2009.

Figure 4. Percent of Transportation Supply Source—2008

As has been the subject of many well documented reports including the *Report of the Defense Science Board Task Force on DoD Energy Strategy* (AT&L—February 2008) and the Center for Naval Analyses (CNA Corporation) *National Security and Threat of Climate Change Study Report* (2007), such a dependency on petroleum-based supply sources represents a significant national security threat. In addition, as public and policy concern for environmental ramifications on climate change caused by fuel-burning combustion engines continues to grow, a need to find alternative fuels and technologies to meet U.S. transportation consumption requirements continues to be the subject of much focus. Recently, the Center for Strategic and International Studies (CSIS) and the National Renewable Energy Laboratory (NREL) published their report titled, *Alternative Transportation Fuels and Vehicle Technologies* (August 2009), which listed and described several emerging liquid fuels and vehicle technologies that are the subject of much national and global research, development, and investment.

This IDA study incorporates the listing of the fuels and technologies considered in the CSIS/NREL study, but also expands the view to consider all fuels listed by EPActs 92/05 as alternative fuels. As it is not within the scope of this study to provide the detailed scientific and technical production methods for each of the fuels and vehicle technologies considered, we merely list the fuel sources and technologies and defer the scientific and technological production descriptions to the appropriate technical reports and subject references. To further aid in the study analysis, these fuels and vehicle technologies are considered separately for ground-based vehicles, air transportation, and maritime shipping.

a. Ground

Alternative Vehicle Fuels and Sources. According to the U.S. DOE's Alternative Fuels and Advanced Vehicles Data Center (AFDC), EPAct 92 lists seven fuels that are currently, or once were, commercially available for vehicles in addition to an equivalent number of emerging alternative fuels. Table 1 below shows the currently available alternative fuels as well as emerging fuels under development.

Table 1. Current and Emerging Alternative Fuels for Vehicles

Current	Emerging
Biodiesel, Electricity, Ethanol, Hydrogen, Methanol, Natural Gas, Propane, Ultra-Low Sulfur Diesel	Biobutanol, Biogas, Biomass-to-Liquids (BTL), Coal-to-Liquids (CTL), Fischer-Tropsch Diesel, Gas-to-Liquids (GTL), Hydrogenation-Derived Renewable Diesel (HDRD), P-Series, Air-Hybrid

Source: DOE AFDC

While all fuels listed in Table 1 are considered to be an alternative to current petroleum-based vehicle gasoline, their production processes and the feedstocks used to produce a gasoline gallon equivalent (GGE) are vastly different. The CSIS/NREL study and the JASON's *Reducing DoD Fossil-Fuel Dependence* (JSR-06-135—September 2006) provide adequate summaries of the production processes and technological challenges encountered by each of the listed fuel types, including the challenge of dealing with the waste byproduct of each. Table 2 summarizes the feedstocks for each as it addresses the availability of a domestically produced supply source, the goal of which would be to reduce the current dependence on a petroleum-based supply source as was described previously and shown in Figure 4.

Table 2. Alternative Fuel Types and Primary Feedstocks

Fuel	Feedstock	Fuel	Feedstock
Methanol	Natural Gas (MTBE)	Biobutanol	Corn, sugar beets, grasses, agricultural waste products
Ethanol	Corn grain (starch), sugar cane (sugar), (cellulosic) grass, wood, crop residues, newspapers	Biogas	Animal manure, sewage, and municipal solid waste
Natural Gas	Hydrocarbons (methane)	Biomass-to-liquids (BTL)	Biomass product processing
Propane	Propane	Coal-to-liquids (CTL)	Coal product processing
Biodiesel	Vegetable oils and animal fats	Fischer-Tropsch diesel	Natural gas, gasified coal, biomass
Hydrogen	Hydrogen	Gas-to-liquids (GTL)	Natural gas product processing
Ultra Low Sulfur Diesel	Diesel fuel with 15 parts per million or lower sulfur content	Hydrogenation-derived renewable diesel (HDRD)	Fats and vegetable oil

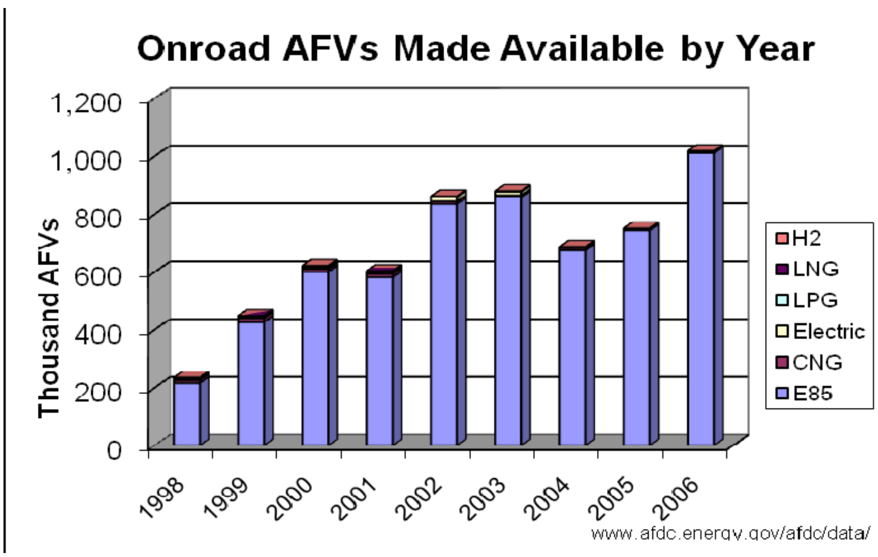
Beyond the cost of the industrial production of alternative fuels, including capital expenditures, one of the primary drivers in adopting alternative fuels is the price compared to a gasoline gallon equivalent (GGE). For the currently available fuels, the 2008 nationwide average price of ethanol (E85) was listed at $3.99/GGE, propane at $4.67/GGE, biodiesel (B20) at $3.69/GGE, and compressed natural gas (CNG) at $2.01/GGE.[6] This is compared to $3.04 per gallon of petroleum-based gasoline. Given the price/gallon differences, the economics of transitioning to an alternative fuel source in liquid form has not been reached. Problems of regional availability, supply infrastructure, and distribution also contribute to their higher costs. These issues are discussed later in this report.

Hybrids and Alternative Drive Technologies. Given some of the challenges of mass producing and distributing alternative liquid fuels on an economical scale, many within the transportation sector have addressed the petroleum-based supply source

[6] Department of Energy, *Clean Cities Alternative Fuel Price Report*, October 2008.

challenge through development of hybrid and alternative drive technologies. These technologies attempt to reduce the demand for liquid fuel by engineering electrical, mechanical, chemical, and systems solutions to extend vehicle performance in terms of miles per gallon (MPG) of gasoline. Current solutions vary from changing the weight/wake properties of heavy vehicles, developing hybrid-electric and plug-in hybrid-electric vehicle (HEV/PHEV) drives, improving fuel cell technology, creating flex fuel engines, developing solar/electric propulsion systems, and designing fully electric drive train technologies.

According to recent statistics, HEV sales and adoption is increasing due to various tax credits and rebates (e.g., Cash Allowance Rebate System—CARS 2009). Historically, the Toyota Prius leads all HEV makes and models in U.S. sales with more than 674,000 units sold.[7] However, E85 flex fuel vehicles continue to lead the market in availability. Figure 5 shows the number of vehicles available by alternative fuel vehicle (AFV) type from 1998-2006. This trend is perhaps a result of the higher average per unit cost of HEV vehicles versus conventional flex fuel technology. Also, playing a large role in this statistic is the higher adoption of flex fuel vehicles by fleet services (e.g., mass transit, Government, and military light-duty vehicles).



Source: AFDC, 22 August 2008.

Figure 5. Alternative Fuel Vehicles (AFVs) Available

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7 DOE-AFDC, *HEV Sales by Model*, 15 January 2009.

Of greater importance to DoD ground-vehicle capabilities and requirements are the emerging technologies in heavy duty (trucking and bus) vehicle design. Military vehicles have the primary requirements of survivability, force protection, increased payload carrying, and towing capacity. This typically results in heavier vehicles with significant engine propulsion requirements. The DOE's 21st Century Truck Partnership is an effort focused on "safely and cost-effectively moving larger volumes of freight and greater numbers of passengers while dramatically reducing dependency on foreign oil."[8] The specific technology goals of the partnership include improving diesel engine efficiency, designing a heavy duty (>8,500 pound gross vehicle weight) hybrid electric propulsion-based vehicle, reducing vehicle parasitic losses (improved aerodynamics), integrating idling-reduction systems, and increasing vehicle safety through collision avoidance technology. Given the operational parallels between the trucking industry and military operations, significant opportunity exists for vehicle technology transfer between this partnership and DoD. More information will be included in Chapter IV.

b. Air

The global air transportation industry represents a significant consumer of liquid fuels. Passenger airlines account for approximately 85 percent of gallons consumed by U.S. airlines, which account for an estimated 35 percent of global airline fuel consumption.[9] The cost of supplying air travel jet fuel typically trends that of crude oil. Figure 6 shows the average cost of a barrel of jet fuel compared to that of crude oil. We note that the U.S. airline industry paid almost $165/barrel for jet fuel, approximately $30 above crude oil prices of $135/barrel. The additional cost of the jet fuel comes not only from refinery profits, but also from the true cost of refining the crude oil and separating out the Jet A and Jet A-1 grade liquid fuel. With a minimum additional cost (~$0.05) in additives, Jet A and Jet A-1 fuel can be used to produce DoD jet fuels such as JP-8 and JP-8 +100.[10]

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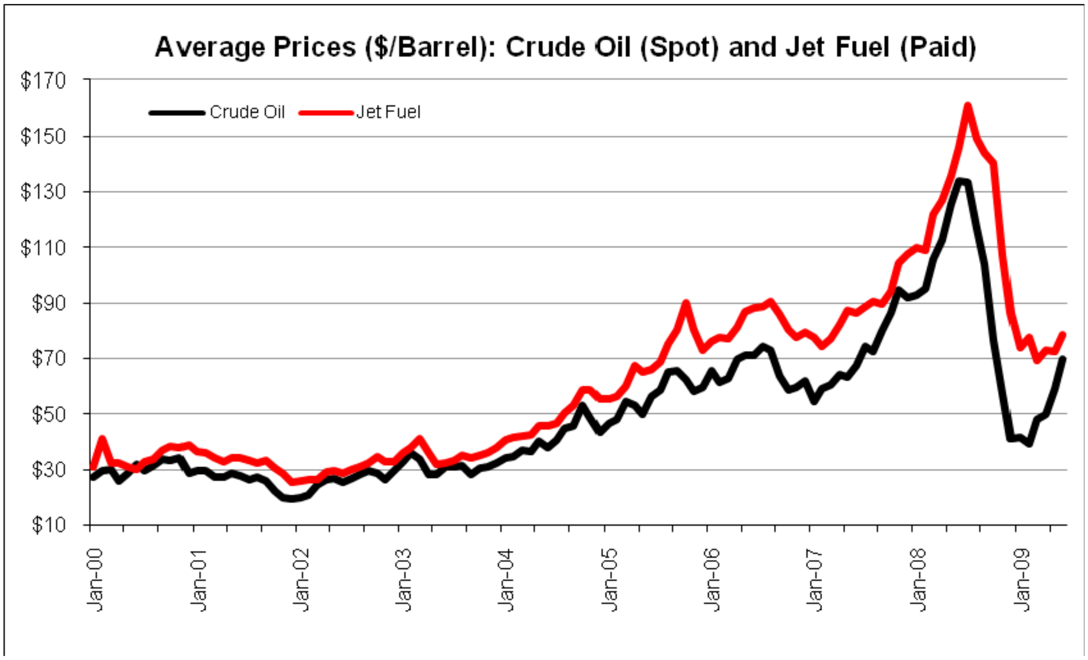
[8] DOE, 21st Century Truck Partnership, *Roadmap and Technical White Papers*, 21CTP-0003 (December 2006).

[9] Airlines.org, http://www.airlines.org/economics/energy/MonthlyJetFuel.htm.

[10] JASONS, *Reducing DoD Fossil Fuel Dependence*, JSR-06-135 (September 2006).



Source: Air Transport Association, Fuel Cost and Consumption Report, June 2009

Figure 6. Average Price of Crude Oil and Jet Fuel

To counter the direct relationship in jet fuel costs to that of crude oil, the airline industry has begun to consider alternative fuels and technologies to improve fuel efficiency and, as a secondary motivation, to reduce their carbon footprint. Advances have been made in synthetic fuels, improved jet engine designs, reduced inflight weight and parasitic losses, and onboard fuel cells for power control. Notable efforts include those of the GE Aviation and NASA "open rotor" jet engine (GE36) and that of the Boeing and UOP (Honeywell) Sustainable Aviation Fuel User Group biofuels derived from algae and jathropa.[11] The U.S. Air Force has also performed several test flights using a 50/50 synthetic fuel blend on a B-52 Stratofortress, a C-17 Globemaster III, and, more recently, a B-1B Bomber at supersonic speed.[12]

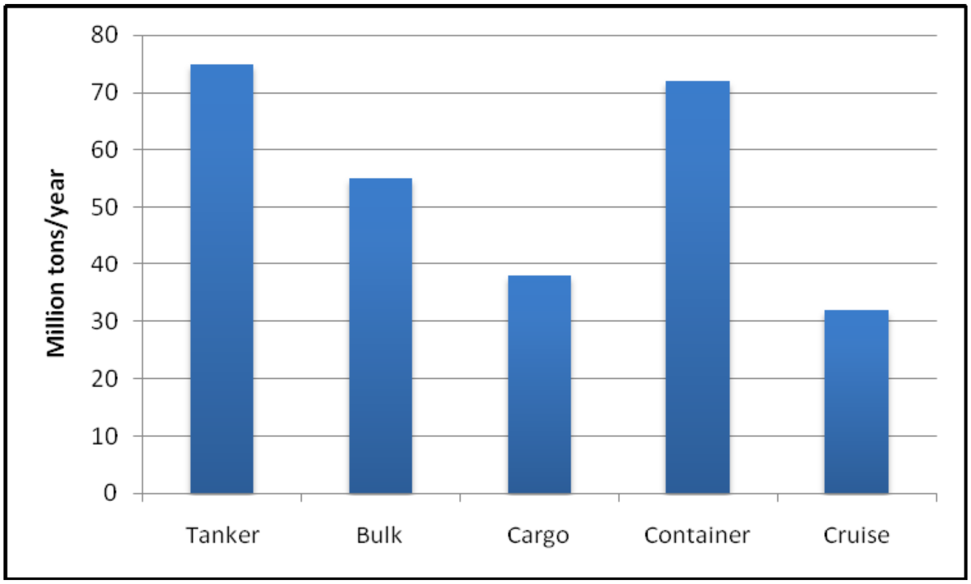
c. Maritime

One of the largest consumers of diesel fuel and residual fuel products is the marine shipping industry. According to the International Maritime Organization (IMO),

[11] Ecofriendlymag.com, http://www.ecofriendlymag.com/general-green-news/ge-nasa-to-test-hybrid-jet-engine.

[12] USAF News Agency, http://www.af.mil/news/story.asp?id=123090913.

the total worldwide fleet fuel consumption in 2008 was approximately 330 million tons, or approximately 20 percent of total global liquid fuel consumption.[13] Figure 7 shows marine fuel consumption by ship category. Industries responsible for shipping bulk goods to the global trade markets, such as tankers and container ships, account for well over 50 percent of the total consumption.



Source: IMO GHG Study 2008/09

Figure 7. Marine Fuel Consumption by Ship Category

Associated with this consumption is the corresponding environmental effect on carbon emissions and marine life. According to the National Oceanic and Atmospheric Administration (NOAA), the shipping industry emits 2.2 million pounds of particle pollution each year.[14] As a result, international maritime organizations, Government agencies, and private industry have initiated efforts in alternative fuels and technologies for maritime shipping. Similar to the heavy-duty trucking and airline industries, initial efforts have focused on improving energy efficiency through improved engine propulsion systems, sleeker ship-hull designs to reduce friction, better ship-route planning, and the

[13] International Maritime Organization, *Greenhouse Gas Study 2008/2009* (MEPC 58/INF.6).

[14] NOAA, *Maritime Shipping Makes Hefty Contribution to Harmful Air Pollution*, 26 February 2009.

use of marine/synthetic fuel blends. Notable efforts include Subsea Industries' innovative hull coating, Ecospeed, used to reduce the friction of a ship as it moves along the ocean surface.[15] Another significant effort is the U.S. Navy's All-Electric propulsion system, which consists of an American Superconductor Co./Northrop Grumman 36.5-megawatt (MW) high-temperature superconductor (HTS) ship propulsion motor.[16] The HTS motor is capable of outputting 49,000 horsepower using superconductor wires in the motor drive and is highly efficient at the low speeds suited for most U.S. Navy operations. In addition, the DoD has developed several nuclear-powered ships (e.g., USS *Ronald Reagan)* and submarines as a part of its active fleet.

3. Portable Power and Battery Technologies

In light of current military operations in Iraq and Afghanistan, portable power and battery technologies have become an increasing focus of DoD military systems, logistics, and operations planning personnel. Commercially, portable power (generators) and battery technologies have continued to evolve as new battery chemistries, such as lithium-polymers, have been introduced into the marketplace to meet the demands of longer-life portable electronics devices. Similarly, portable-power generation for military forward operating bases and battery technologies for mobile solider communications radios and tactical devices continues to be a critical component in successfully meeting mission objectives.

a. Portable Power (Generators)

To date, most portable-power (generator) systems primarily use a petroleum-based liquid fuel or an AC electric source. Few advances have been made in the adoption of an alternative energy source, fuel, or technology in this sector. However, more recently, notable efforts in the commercial sector have included the use of fuel cells for off-grid power generation and portable/deployable solar cell arrays. In addition, the U.S. Army has invested in thin-film solar arrays and biomass generators for fixed infrastructure alternative power generation.[17]

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15 MarineTalk.com, http://www.marinetalk.com/articles-marine-companies/art/Ecospeed-Reduces-Ships-Fuel-Consumption-SUB009111301TU.html.

16 NationalDefenseMagazine.org, *Ambitions of All-Electric Navy Get Reality Check*, June 2009.

17 Army Environmental Policy Institute, *Use of Renewable Energy in Contingency Operations*, March 2007.

b. Battery Technologies

Battery technologies have continued to evolve as more and more portable electronic devices have penetrated the marketplace. Primary battery chemistries such as alkaline-based batteries continue to be the most widely sold battery technology. Secondary (rechargeable) battery chemistries, such as lithium-ion and lithium-polymer, have also evolved and have gained greater market share. Of technical importance to this study is the energy density afforded by each of the battery technologies. Figure 8 shows the average power-to-volume versus average energy density of the leading secondary (rechargeable) battery chemistries. From the figure, lithium-polymer batteries are seen to provide the highest level of stored energy by volume (vertical axis) and weight (horizontal axis). This is extremely important as the warfighter portable-power requirements typically require maximum stored energy capacity while minimizing the size and weight. Note also that nickel cadmium (NiCd) batteries are banned from use in Europe due to the hazardous environmental waste associated with the disposal process.

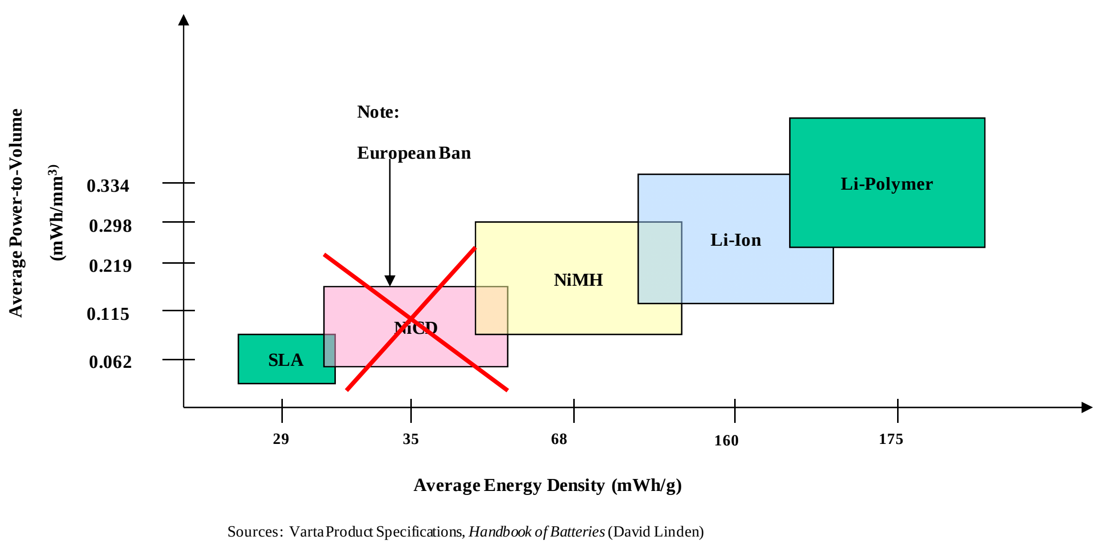

Figure 8. Rechargeable Battery Energy Density Comparison

Small lightweight portable power afforded by battery technologies is becoming a critical part of the battlespace. In the early days of the Persian Gulf War, one of the primary hindrances to operational efficiency was the lack of battery packs for the deployed forces. This was made even more critical because the available packs were primarily constructed of a primary battery chemistry and were not rechargeable in the field. The inability to charge the packs posed operational constraints as the battery-charge levels dropped below operational levels and new supplies were needed. In addition, disposing of such packs also posed an environmental issue to deployed forces.

To address the significantly vital role battery packs and portable-power technologies are making to the warfighter, the DoD has begun to invest in alternative energy sources, fuels, and technologies to replace or complement existing portable-power technologies. Recently, the DoD conducted a wearable-energy contest that pitted competing fuel-cell technologies in wearable soldier packs against each other.[18] The goal of the competition was to produce a minimum of three alternative competing technologies for a soldier power pack that would meet minimum weight and maximum operational time requirements posed by today's power-hungry warfighter communications and computing devices.

B. MATURITY-LEVEL ASSESSMENT AND ANALYSIS

Before evaluating and considering the adoption of the alternative energies, fuels, and technologies discussed in the previous section, it is important to conduct a technology maturity-level assessment and analysis. The maturity-level assessment process must consider all pertinent aspects of developing, adopting, distributing, and maintaining the technology. In addition, an approach for continuous improvement is critical to market growth, wider adoption, and reduced costs, including the fully burdened cost (FBC) of deploying the new energy, fuel, or technology. In this study, we have attempted to conduct a technology maturity-level assessment and analysis for the commercial sector and for military applications. For the commercial market, the study defines a process called the Technology Maturity Assessment Wheel (TMAW) and, for military applications, an attempt is made to use DoD-approved technical maturity and technology readiness level (TRL) categories.

To assign a commercial sector maturity-level value to each of the alternative energy sources, fuels, and technologies described above, the study defined the TMAW shown in Figure 9. The TMAW is a closed-loop system approach to maturity-level assessment and analysis. It considers all primary phases of producing and delivering an alternative energy, fuel, and technology. The primary assessment wheel consists of five

[18] William Matthews, "Wearable-Energy Contest Dominated by Fuel Cells," *Defense News*, 13 October 2008.

main steps, including production, consumption, distribution, maintenance, and process/technology improvement. The inner portion of the TMAW consists of risk analysis conducted for each of the primary assessment wheel components. Environmental impact analysis is conducted for all aspects of the primary assessment wheel and the inner risk analysis wheel. Each aspect of the TMAW is described below.

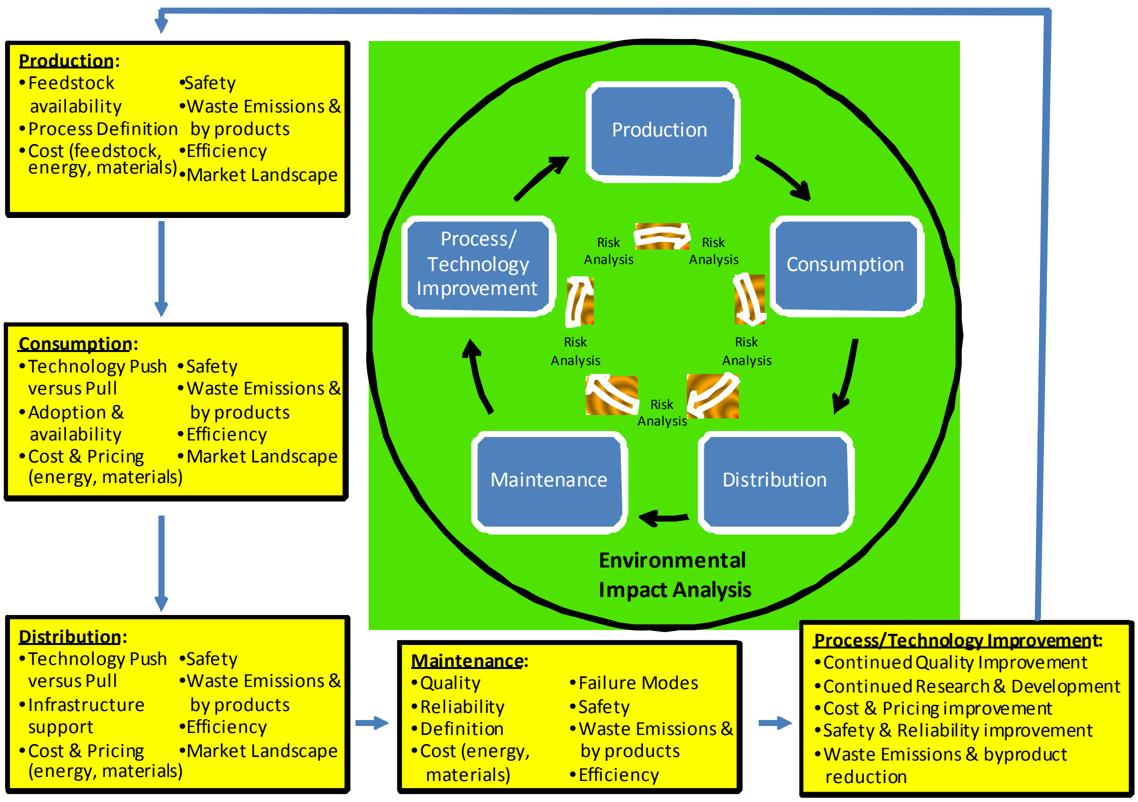

Figure 9. Technology Maturity Assessment Wheel (TMAW)

1. Production

The production phase of the TMAW considers aspects of producing an alternative energy source, fuel, and/or technology. Specifically, consideration is given to issues of feedstock availability (foreign or domestic), how well the production process is defined and understood, the cost of production (feedstock, energy, and materials), safety, and efficiency. Consideration is also given to the market landscape in terms of the number of producers, manufacturers, and suppliers. From the environmental impact analysis perspective, consideration of waste emissions, resulting byproducts, and efficiency are considered.

2. Consumption

The consumption phase of the TMAW considers aspects of how the alternative energy source, fuel, and/or technology is consumed in the global marketplace. Consideration is given to whether there exists a technology “pull or push” relationship driving consumption (i.e., market versus industry driven), adoption and availability in global or regional markets, cost and pricing, safety, and efficiency. Consideration is also given to the market landscape in terms of the number and breadth of users. From the environmental impact analysis perspective, consideration of waste emissions, resulting byproducts, and efficiency are considered.

3. Distribution

The distribution phase of the TMAW evaluates aspects of how the alternative energy source, fuel, and/or technology is distributed and delivered into the global and regional marketplace. Consideration is again given to whether there exists a technology “pull or push” relationship, adequacy of the infrastructure to support delivery of the alternative energy source, cost and pricing, safety, and efficiency. Consideration is also given to the market landscape in terms of the number and breadth of suppliers, distributors, and wholesalers. From the environmental impact analysis perspective, consideration of waste emissions, resulting byproducts, and efficiency are considered.

4. Maintenance

The maintenance phase of the TMAW evaluates aspects of maintaining the source of the alternative energy, fuel, and technology. Aspects of product quality, reliability, definition of maintenance cycle requirements, cost, safety, and efficiency are all considered in this phase. Consideration is also given to the failure modes of the technology (i.e., level of catastrophic failure, effect on the user and environment). From the environmental impact analysis perspective, consideration of waste emissions, resulting byproducts, and efficiency are considered.

5. Process/Technology Improvement

The final phase of the TMAW is the process/technology improvement phase. This phase looks at continuous quality improvement in all aspects of an alternative energy source, fuel, and technology. Primarily, investment in continued research and development, cost and price reduction, improved safety and reliability, and reduced waste emissions and byproduct production.

6. Risk Analysis

The inner wheel of the TMAW is risk analysis, which is conducted at all phases of the primary wheel. Risk analysis can include production risks such as feedstock shortages, consumption risks such as price fixing and emissions, distribution risks such as terrorist attacks or natural disasters resulting in infrastructure damage, and maintenance risks such as unanticipated catastrophic failure modes (i.e., due to climate change).

In order to conduct a numerical technology maturity comparison between the different alternative energy sources, fuels, and technologies, the TMAW assigns a scoring of 1-5 for each phase of the primary wheel: production, consumption, distribution, maintenance, and process/technology improvement. A level of one indicates that the energy source, fuel, and/or technology is in very early stages of maturity and a level of five indicates that it has reached well-understood maturity at that phase. Figures 10-15 summarize the results of the commercial sector technology maturity-level assessment using the TMAW.

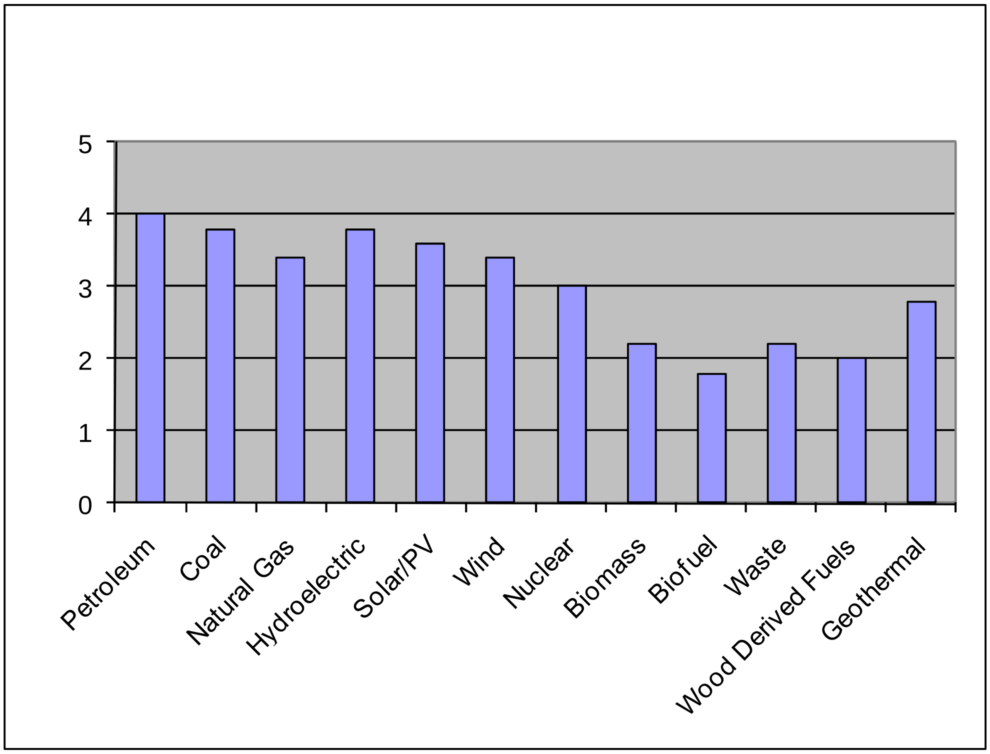

Figure 10. Fixed Infrastructure Technology Maturity Assessment Using the TMAW

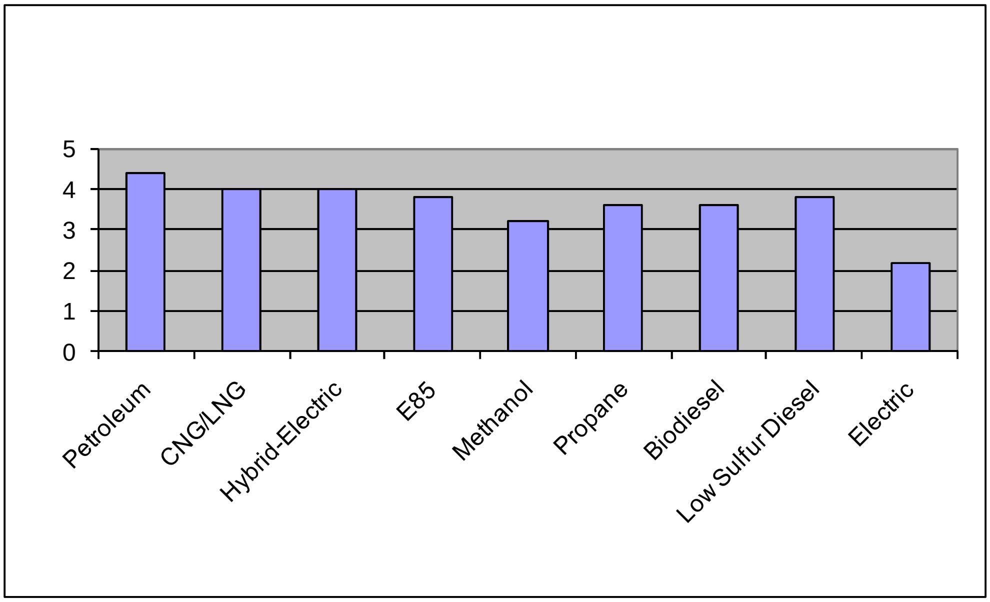

Figure 11. Existing Vehicle Fuel Technology Maturity Assessment Using TMAW

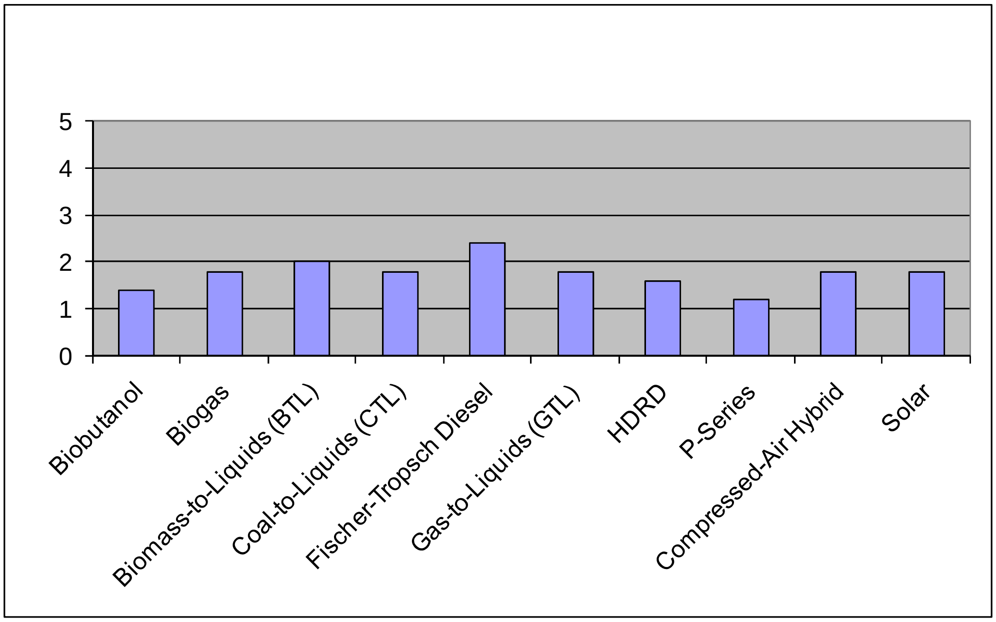

Figure 12. Emerging Vehicle Alternative Technology Maturity Assessment Using TMAW

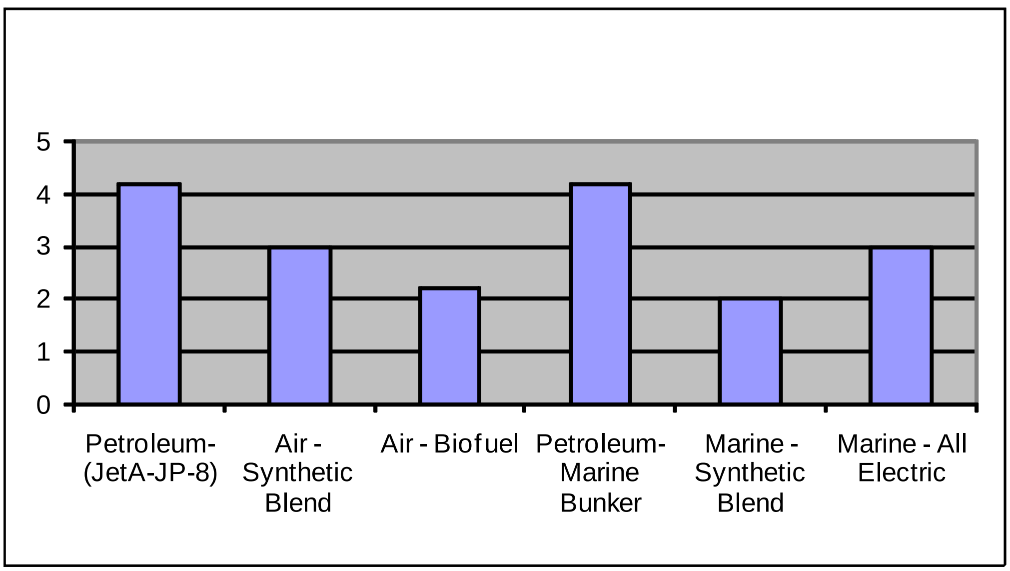

Figure 13. Air and Marine Technology Maturity Assessment Using TMAW

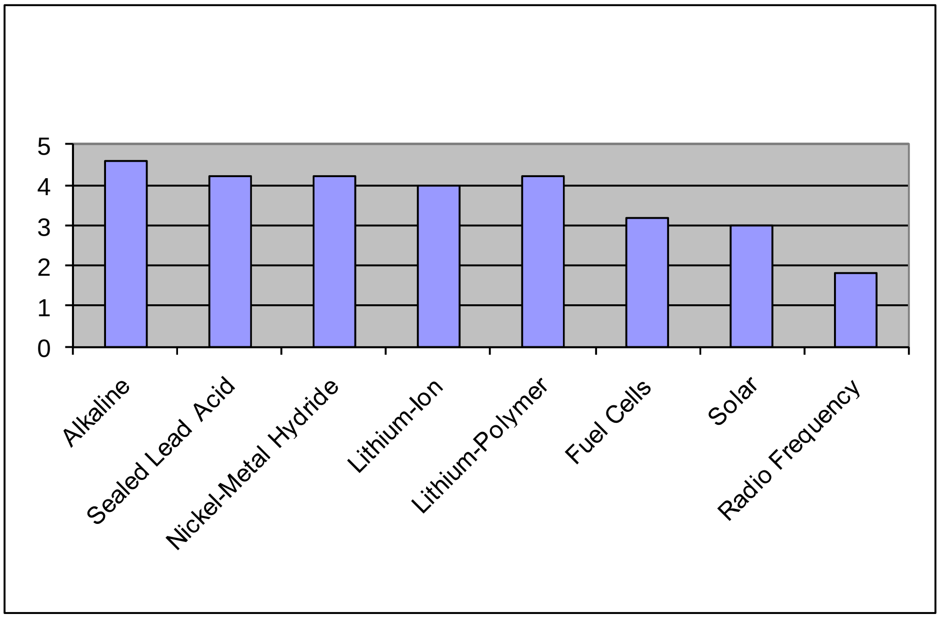

Figure 14. Battery Technology Maturity Assessment Using TMAW

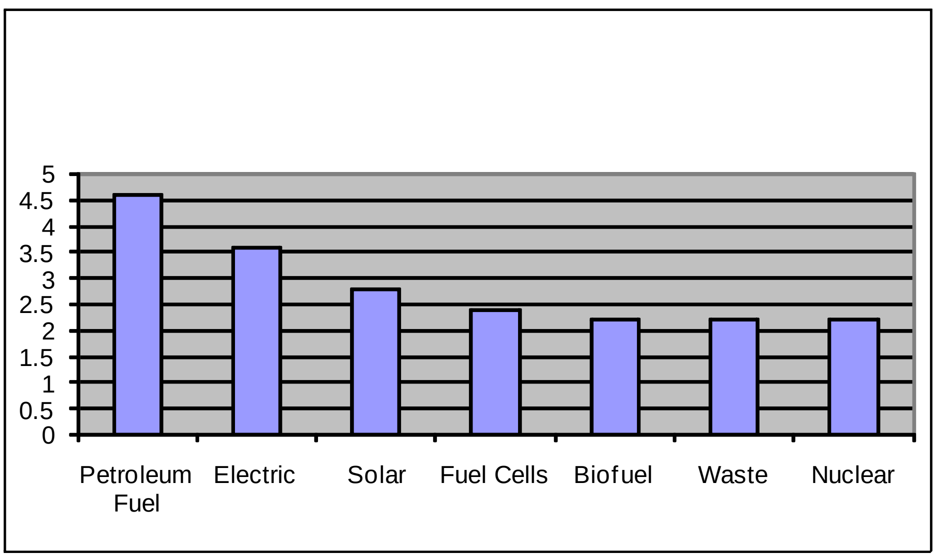

Figure 15. Portable-Power Technology Maturity Assessment Using TMAW

C. MILITARY TECHNOLOGY MATURITY ASSESSMENT (TMA) AND TECHNOLOGY READINESS LEVEL (TRL)

The previous section of this report developed and described the use of the TMAW to assess the technical maturity of existing and emerging alternative energy, fuel, and technology sources. In addition, examples of fixed infrastructure energy sources, vehicle fuels and technologies, and portable power technologies were examined using the TMAW to assess their level of commercial maturity given the primary assessment categories of the TMAW (production, consumption, distribution, maintenance, and process/technology improvement). This section examines the same technologies, but from a DoD technology maturity assessment (TMA) and technology readiness level (TRL) perspective.

The Defense Acquisition Guidebook describes nine possible TRLs for critical technologies under program consideration. TRL 1 represents technologies primarily described in technical papers but not realized in an experimental capacity; TRL 9 represents technologies that have been successfully demonstrated in mission operations.[19] Many of the alternative energies, fuels, and technologies considered in this report have not achieved a TRL-9 status, but can be assigned a TRLs level based on the descriptions found in the Defense Acquisition Guidebook. Table 3 shows estimated TRLs as assigned in this study. It should be noted that these are merely estimated levels based on reviewed publicly available information of DoD efforts using the respective energy, fuel, and technologies and not a formal TRL assignment. A more detailed study would be required to complete a formal TRL assessment using program and technology analysis.

It is important to note that the TMAW takes an end-to-end product life cycle approach, including environmental impact and risk analysis, to assess the renewable energy sources and technologies. Per the Defense Acquisition Guidebook, current DoD TRL assignments are made for each of the identified critical technology components as they make their way from the technical paper descriptions through the laboratory and into a final system. No inclusion of backend production (e.g., feedstock and material availability), distribution (e.g., logistics), and environmental impact issues are accounted for in the current TRL process. This presents an opportunity for incorporating aspects of the TMAW into current DoD TRL assessment processes to aid in fully evaluating an alternative energy, fuel, and/or technology as a viable acquisition option.

From the technology maturity assessment and readiness level results of Figures 10-15 and Table 3, it can be seen that the diverse alternative energy sources, fuels, and/or technologies considered in this study are at vastly different levels of maturity.

[19] DoD, *Defense Acquisition Guidebook*, 2006.

Furthermore, petroleum-based fuel sources consistently rated highest in achieved maturity levels. As a result, most, if not all, primary DoD fixed infrastructure, ground, air, maritime, and portable power systems used today employ some form of energy or fuel source that is derived from a petroleum-based feedstock. As described previously in this report, this dependence on petroleum-based sources can present a significant risk to current and future military systems, logistics, and operations. To address this risk, it is important to begin assessing the various alternative energy sources, fuels, and technologies for potential investment and future use within the DoD. To do so, clear metrics that allow for a quantitative comparison of competing renewable energy technologies and an integrated evaluation method can aid in such analysis.

Table 3. Estimated TRLs of Existing and Emerging Energy Sources, Fuels, and Technologies

Fixed Infrastructure	TRL Level (Est.)	Vehicle Fuels & Technologies	TRL Level (Est.)	Air Fuels	TRL Level (Est.)	Batteries	TRL Level (Est.)
Petroleum	9	Petroleum	9	Petroleum–(JetA-JP-8)	9	Alkaline	9
Coal	9	CNG/LNG	9	Air–Synthetic Blend	7	Sealed Lead Acid	9
Natural Gas	9	Hybrid-Electric	3	Air–Biofuel	4	Nickel-Metal Hydride	9
Hydroelectric	9	E85	9			Lithium-Ion	9
Solar/PV	6	Methanol	5	**Marine Fuels**		Lithium-Polymer	9
Wind	6	Propane	5	Petroleum-Marine Bunker	9	Fuel Cells	6
Nuclear	3	Biodiesel	9	Marine–Synthetic Blend	4	Solar	5
Biomass	5	Low Sulfur Diesel	3	Marine–All Electric	7	Radio Frequency	2
Biofuel	5	Electric	3	Nuclear	9		
Waste	6	Biobutanol	3			**Generators**	
Wood Derived Fuels	5	Biogas	3			Petroleum Fuel	9
Geothermal	8	Biomass-to-Liquids (BTL)	3			Electric	9
		Coal-to-Liquids (CTL)	3			Solar	5
		Fischer-Tropsch Diesel	4			Fuel Cells	4
		Gas-to-Liquids (GTL)	3			Biofuel	4
		HDRD	1			Waste	4
		Solar	2			Nuclear	3
		Compressed–Air Hybrid	1				

III. DEFINING METRICS FOR THE QUANTITATIVE COMPARISON OF ALTERNATIVE ENERGY, FUELS, AND TECHNOLOGIES

As highlighted in Chapter II, the different alternative energy sources, fuels, and technologies surveyed here are at vastly different levels of technical maturity as rated using the TMAW developed in this study and per the DoD TRL guidance. To adequately compare inter- and intra-technology options, it is necessary to define a common list of metrics for which competing technologies can be assessed. This section describes the Hierarchical Evaluation Metrics Tree (HEMT), which takes a hierarchical approach to the generation of a comparison metrics list for each of the energy-consuming sectors. The tiered approach consists of a top-level Evaluation Metrics Requirement, followed by a middle-tier, which groups metrics into class types, and finally, the lowest tier is constructed of detailed and quantifiable area metrics. Figure 16 shows the HEMT.

The HEMT is a flexible approach to deriving quantifiable metrics for the comparison of alternative energy sources, fuels, and technologies. The goal of the HEMT is to develop a list of metrics that permits an unbiased comparison of technologies that may be at vastly different technical maturity levels. It is a method that can be modified and expanded depending on the technology being considered. The key components of the HEMT are the Evaluation Metrics Requirements, metric class types, and quantifiable metric areas.

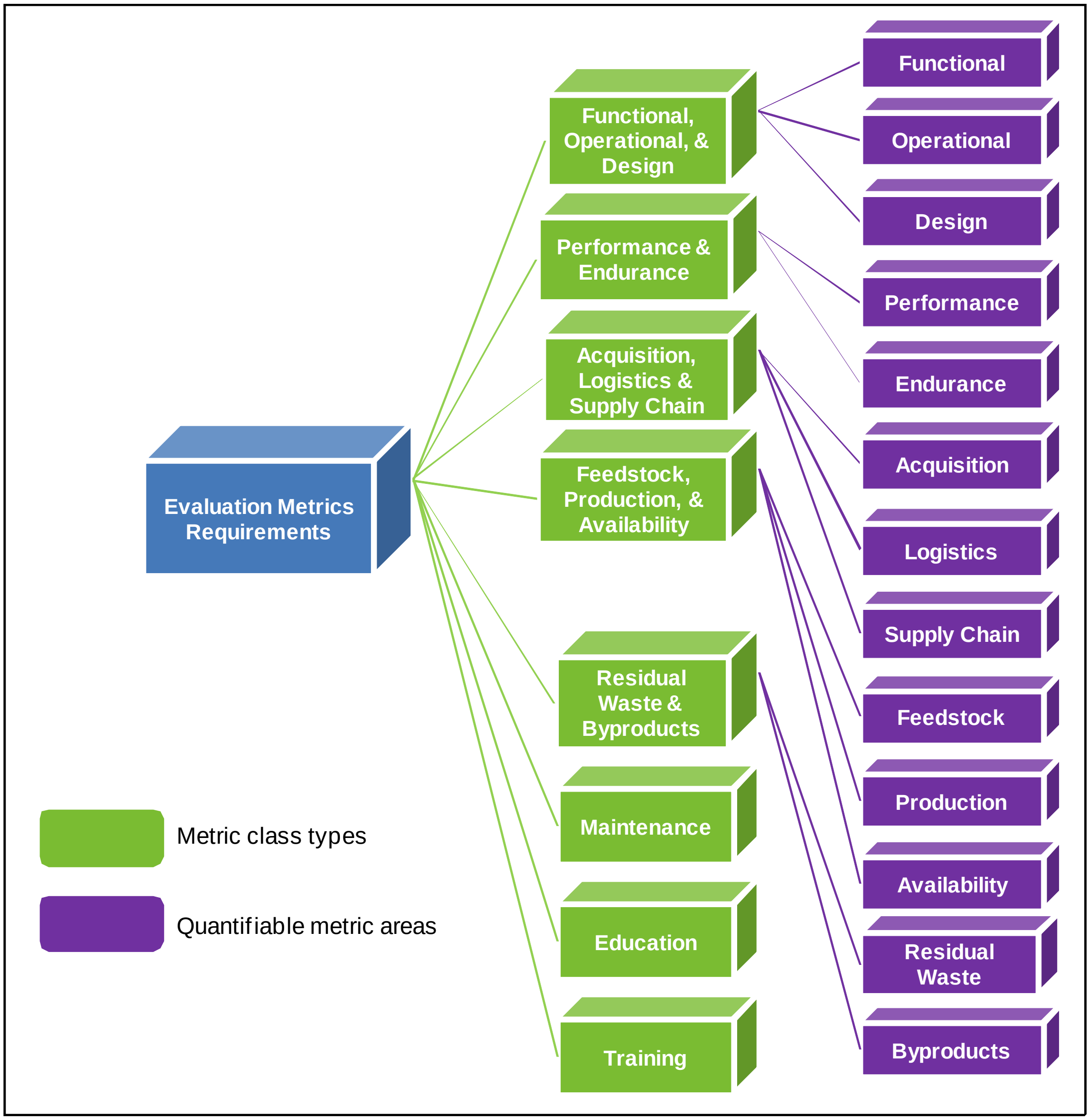

Figure 16. Hierarchical Evaluation Metrics Tree (HEMT)

The starting point of the HEMT is the Evaluation Metrics Requirements (EMR) list. The EMR list defines a set of high-level system, operational, and/or technical requirements that must be met by the alternative energy source, fuel, or technology under consideration. As examples, we may consider the following DoD high-level requirements such as "develop a next generation vehicle that improves mission effectiveness through improved survivability, reduced logistics demand, and supply chain burden" or "improve forward operating base sustainability by creating more efficient and self-sustaining power generation sources." While both of these requirement examples are very broad, they are used as starting points to begin the creation of defined comparison metrics. This study defines eight primary comparison metric classes. For each, sector-based examples are presented in Appendix C.

A. FUNCTIONAL, OPERATIONAL, AND DESIGN METRICS

The functional, operational, and design metrics are a class of metrics that encompass the technical aspects of how an alternative energy source, fuel, or technology will meet the EMR list. These metrics include technical details of the technologies being evaluated and are dependent on the sector being considered (e.g., fixed infrastructure, vehicle alternative fuels/technology, air, maritime, or portable power). As examples, one may consider the miles per gasoline gallon equivalent when considering an alternative vehicle fuel or the ampere-hour per gram when considering an alternative portable-power technology. More detailed functional, operational, and design metric examples specific to DoD needs are listed in Appendix C.

B. PERFORMANCE AND ENDURANCE METRICS

Performance and endurance metrics address the requirements of the alternative energy source, fuel, and/or technology being evaluated to meet a minimum reliability, safety, quality, and mean time between failure (MTBF) values. Operational stress testing metrics to evaluate the operational limits of a technology under evaluation also form part of this class of metrics. As with the functional, operational, and design metrics, the performance and endurance metrics are also sector-based and examples are listed in Appendix C.

C. ACQUISITION, LOGISTICS, AND SUPPLY CHAIN METRICS

The acquisition, logistics, and supply chain metrics class type defines comparison metrics that can be used to determine the cost, pricing, logistics requirements, supply chain, and distribution needs of an alternative energy source, fuel, and technology. Cost can be evaluated as the direct cost of obtaining the technology or the fully burdened cost, which includes the commodity price for the fuel, plus the cost of the people and assets required to move and protect fuel from the point of purchase to the final end user.[1] Logistics metrics look at transportation and storage comparison metrics that establish competitive insight into delivering the energy source, fuel, and/or technology. Similarly, supply chain metrics consider the infrastructure in place or required to effectively and efficiently deliver the energy, fuel, or technology to the end user.

D. FEEDSTOCK, PRODUCTION, AND AVAILABILITY METRICS

Feedstock, production, and availability metrics consider the competitive comparison of an alternative energy source, fuel, and/or technology by evaluating feedstock availability, production complexities, and availability risks. Issues of market availability, single sourcing, and regional availability are also considered. As is evident in today's commercial and military operations, feedstock inventory and production capacity are two very important metrics derived in this metric class type.

E. RESIDUAL WASTE AND BYPRODUCTS METRICS

The residual waste and byproduct metric class type evaluates alternative energy sources, fuels, and technologies based on their overall environmental impact. Detailed comparison metrics in this class type can include process waste (byproducts), production emissions, consumption emissions, and production footprints. As an example, one can consider the amount of acres required by a solar or wind farm to generate an equivalent kilowatt of electricity. This metric class will become increasingly important as carbon emission limits begin to be imposed on producers and consumers of energy.

F. MAINTENANCE METRICS

The maintenance metric class type considers all aspects of maintaining and servicing an alternative energy source, fuel, or technology. Maintenance cycles, complexity, process, and refurbishment are all considered in this metric class type. Volatility and efficiency curves can also be considered.

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1 *The Fully Burdened Cost of Delivered Fuel Volume I: Pilot Program Reviews*, IDA Document D-3553, April 2008.

G. EDUCATION METRICS

An often overlooked metric is the level of knowledge and understanding of an alternative energy source, fuel, and/or technology and its associated processes. The education metric class type attempts to assess the level of industrial knowledge, investment in research and development, and continuous improvement. As examples, one may project the evolution of a technology under evaluation by analyzing the amount of Government, academic, and private investment in enhancing and improving the understanding of a technology. Large investments may lead to further discovery, which may help differentiate between competing technologies.

H. TRAINING METRICS

The final metric class type defined in this study is the training metrics class. These metrics assess the availability of training sources, personnel, and processes on the understanding, servicing, maintenance, and repair of alternative energy sources, fuels, and technology under evaluation. Skills, knowledge, and ability (SKA) requirements can be considered as well as certification bodies and standards. Labor force availability can also be included as a differentiator and as a component metric for this class type.

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IV. AN INTEGRATED EVALUATION METHOD FOR THE QUANTITATIVE COMPARISON OF ALTERNATIVE ENERGY, FUELS, AND TECHNOLOGIES

In addition to having a clear common set of metrics to effectively compare alternative energy sources, fuels, and technologies, a well-defined evaluation method is required. This study presents the Integrated Evaluation Method (IEM) as a general method for evaluating competing alternative energy sources, fuels, and technologies. It integrates the results of the TMAW described in Chapter II and the HEMT described in Chapter III with commonly accepted market product requirements techniques such as the Quality Function Deployment (QFD) House-of-Quality (HOQ), Six Sigma Define, Measure, Analyze, Integrate, and Control (DMAIC) techniques, Voice-of-the-Customer (VOC), Key Performance Parameter (KPPs) selection, and Critical-to-Quality/-Safety/-Cost (CTQ/CTS/CTC) metric definitions. Additional descriptions of these techniques are provided in Appendix D.

The IEM is defined with a focus on military needs and capabilities. It is a step-by-step process that considers all stakeholder VOC inputs and uses them to develop a comprehensive list of capabilities needs and requirements that an alternative energy source, fuel, and/or technology must meet. The process then prioritizes the needs and requirements based on urgent needs, short-/mid-/long-term needs, and on "must have," "like to have" or "not critical" requirement definitions. (See Figure 17.) Using the output of the TMAW and the HEMT, the needs and requirements are then mapped to the quantifiable metrics listed in the HEMT table. A HOQ is then constructed to provide a quantitative comparison of the alternative energy, fuel, and/or technology solution using the quantified metrics of the HEMT. Results are then evaluated and KPPs and CTQ/CTS/CTC parameters are selected. Finally, a method to monitor and control the IEM process is defined and documented. This chapter describes each of these steps in further detail.

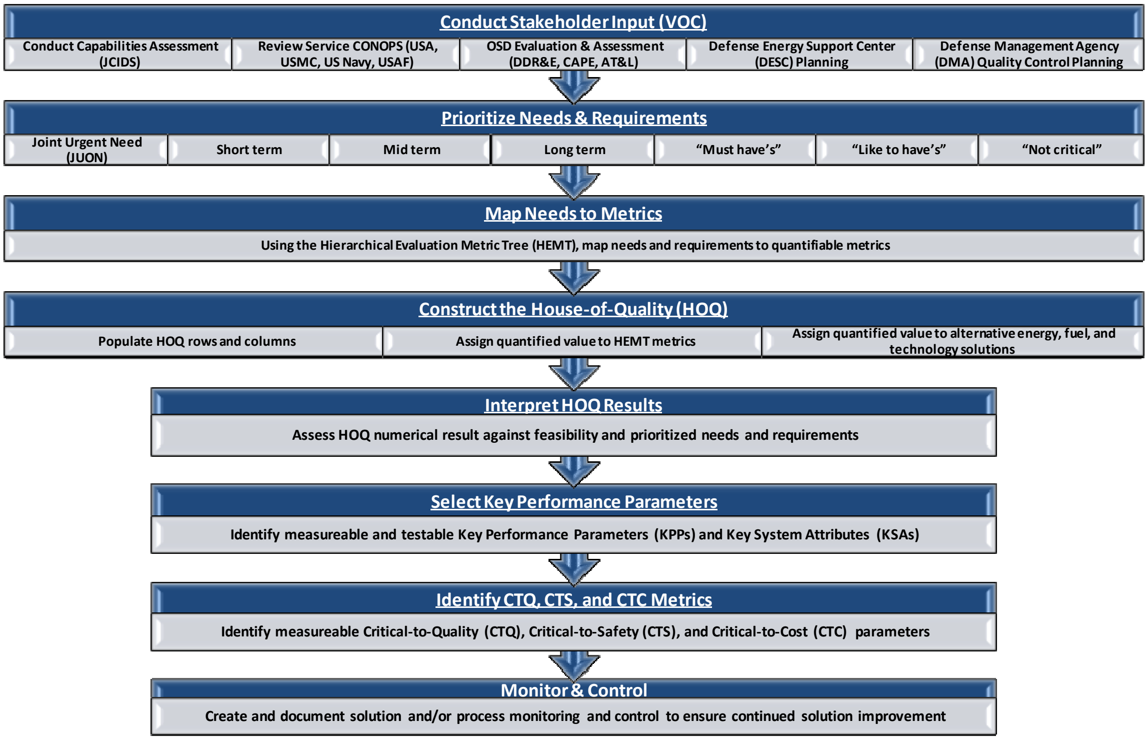

Figure 17. Integrated Evaluation Method (IEM)

A. DEFINING THE HOUSE-OF-QUALITY (HOQ)

One of the key aspects of the IEM defined in this study is the construction of the House-of-Quality. The HOQ uses stakeholder input and a common list of comparison metrics (via the HEMT) to quantitatively compare inter- and intra- alternative energy, fuel, and technology solutions. The output of the HOQ is then a quantified comparison of the available technologies and solutions that can then be used as a means to select the top competitive technologies for further DoD investment and development.

B. DEVELOPING DOD COMMUNITY CAPABILITIES NEEDS AND REQUIREMENTS

As is common in the evaluation and consideration of any new technology, the first step in the IEM is to determine the DoD community capabilities needs and requirements. The IEM proposes conducting VOC surveys within a broad range of DoD stakeholders, including all affected services and OSD offices (DDR&E, AT&L, CAPE, and DT&E).

Input from the JCIDs process is also rolled in as VOC-relevant information. In some case, Joint Urgent Needs (JUONs) are also reviewed for applicability as input.

Since the selection of any new alternative energy source, fuel supply, and/or technology necessarily affects the Defense Energy Support Center (DESC), the IEM also includes DESC VOC feedback. In addition, as the newly selected energy source, fuel, and/or technology is developed, tested, and deployed, quality processes must be in place to monitor and control that the purchased solution meets all requirements. Here, the IEM also includes VOC input at an early stage from the Defense Contract Management Agency (DCMA) to ensure that appropriate quality checks are in place to assess the progress of the selected solution.

C. PRIORITIZING NEEDS AND REQUIREMENTS

With a broad selection of VOC stakeholder inputs, it necessarily follows that there will exist a large and diverse set of requirements that the new alternative energy source, fuel, and/or technology must satisfy. Hence, the next step is to prioritize the needs and requirements into urgent needs, short-term needs, mid-term needs, and long-term needs. As is also common when conducting VOC surveys, "must have," "like to have," and "not critical" categories also emerge. These are easier to identify if a VOC technique such as a Kano survey plot is used. See Appendix D for a discussion and example on Kano surveys.

D. MAPPING OF REQUIREMENTS TO COMPARISON METRICS

Having identified and prioritized the needs and requirements of the new alternative energy source, fuel, and/or technology, the next step in the IEM maps the emerging needs and requirements to the comparison metrics of the HEMT. This step begins the process of quantifying the comparison. All needs and requirements must be mapped to a metric class and subsequently a metric area. At the final level, all needs and requirements must have a metric that contains a quantified value, either quantitatively or qualitatively derived.

E. CONSTRUCTING THE HOUSE-OF-QUALITY (HOQ)

The most important step in the IEM is constructing the House-of-Quality. The construction of the HOQ provides a quantified and systematic approach for comparing the technologies under consideration. This is done by placing the prioritized needs and requirements as row entries in the HOQ and the HEMT quantified metrics in the columns. In addition, the alternative energy sources, fuels, and/or technology options being considered are placed in the planning (competitive analysis) matrix portion of the HOQ. See Appendix D for additional detailed discussion on HOQs. In Chapter V we will consider an example as it relates to military ground vehicles.

F. POPULATING THE HOQ

After constructing the HOQ, the next step is to fill in the HOQ cells with the appropriate scoring value. The inner portion of the HOQ scores the interrelationship between the prioritized needs and requirements and the HEMT-quantified metric. The top cells of the HOQ ("the roof") consider how satisfying one requirement may affect or support the satisfaction of meeting any other requirement. In the planning matrix portion, each of the alternative energy sources, fuels, and/or technologies under consideration are scored from best to worst in terms of their ability to meet or satisfy the prioritized needs and requirements.

G. INTERPRETATION OF HOQ RESULTS FOR COMPARISON RESULTS

The final step in the IEM HOQ process is to interpret and assess the results of the HOQ. As this is a quantified approach, the bottom portion of the HOQ will contain target values for competitive benchmarking and technical priorities. The alternative energy source, fuel, and/or technologies that score the highest against the targets are then selected as potential solutions for further investigation and assessment.

H. SELECTING KEY PERFORMANCE PARAMETERS (KPPS) AND KEY SYSTEM ATTRIBUTES (KSAS)

After the top alternative energy sources, fuels, and/or technologies have been identified using the HOQ, the IEM is then used to identify and select the KPPs and KSAs. KPPs are quantifiable, measureable, and testable performance parameters that can be used to assess whether selected technology is meeting the system technical requirements in a satisfactory way. In addition, the IEM integrates guidance on KSA selection using the JCIDS Manual. An example of this process will be shown in Chapter V.

I. IDENTIFYING CRITICAL-TO-QUALITY/-SAFETY/-COST (CTQ/CTS/CTC) METRICS

Similar to the KPPs and KSAs, the IEM is then used to identify and select the CTQ, CTS, and CTC parameters associated with the selected alternative energy source, fuel, and/or technology. These parameters differ from the KPPs and KSAs in that they directly measure the view and expectation of the selected technology against the stakeholder needs and expectations. CTQ, CTS, and CTC parameters can be associated with solution attributes identified by the stakeholders as critical to the quality of the solution being evaluated, its safety, and cost, including the fully burdened cost of fuel (if applicable).

J. DEFINING MONITOR AND CONTROL PROCESSES

The final step in the IEM is to define the monitor and control processes that will be put in place to assure that the selected alternative energy source, fuel, and/or technology is meeting both the technical and customer requirements. The Six Sigma DMAIC process is recommended here as a part of the IEM. See Appendix D for a brief description of Six Sigma DMAIC techniques.

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V. EXAMPLE: APPLICATION OF PROPOSED INTEGRATED EVALUATION METHOD (IEM) TO MILITARY GROUND VEHICLES

The TMAW, the HEMT, and the IEM developed in this study were designed to be flexible and adaptable to effectively compare varying alternative energy sources, fuels, and technology solutions for the primary energy-consuming sectors described here. Chapter II of this report categorized the primary energy-consuming sectors as fixed infrastructure, vehicles (ground, air, maritime), and portable-power (generators, battery) technologies. While the techniques developed in this study can be applied to all of these sectors, this chapter provides an applied example of the TMAW, HEMT, and IEM to military ground-vehicle fuels and technologies.

A. MOTIVATION – JOINT LIGHT TACTICAL VEHICLE (JLTV) AND ARMY VEHICLE MODERNIZATION PROGRAM

Section 114 of the FY06 Defense Authorization Bill titled “Acquisition Strategy for Tactical Wheeled Vehicle Programs,” provided congressional guidance to the DoD for the procurement of a new vehicle class for the next-generation tactical wheeled vehicle, to be performed under joint development between the U.S. Army and Marines. The result of this guidance was the creation of the JLTV program whose mission was to “jointly develop, produce, field and sustain a safe, reliable, suitable and effective Family of Joint Light Tactical Vehicles (FoVs).”[1]

More recently, military operations in Iraq and Afghanistan led DoD Secretary Robert Gates to redirect funds originally allocated to the ground-vehicle component of the Future Combat Systems (FCS) to the development of the Army Vehicle Modernization Program. In his statements, Secretary Gates indicated that "the premise behind the design of these [FCS] vehicles was that lower weight, greater fuel efficiency and, above all, near-total situational awareness, would compensate for less heavy armor,

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[1] JLTV PM briefing, *JLTV Briefing to Industry*, JLTV Pre-proposal Conference 19-21 February 2008.

[but that premise was] belied by the close-quarters combat, urban warfare, and increasingly lethal forms of ambush that we've seen in both Iraq and Afghanistan, and that we are likely to see elsewhere as other adversaries probe for and find ways to turn our strengths against us."[2]

A report from the Congressional Research Service (CRS) regarding the JLTV recently enumerated several issues regarding the role of the JLTV in light of the new Army Vehicle Modernization Program.[3] Issues included those related to overall cost per vehicle, the role of the Mine-Resistant Ambush Protected (MRAP) vehicles, vehicle weight and transportability. According to the report, the latter two issues have caused serious concern on the part of the Marines that the emerging vehicle designs will fail to meet key expeditionary force operational requirements and may lead to them "opting" out of the joint program. Consequently, the requirements, technology and approach for the vehicle modernization program are now being re-evaluated within the DoD and a competitive bidding process for a new FoV will likely emerge.

The question remains as to whether the next-generation tactical wheeled vehicle requirements will specifically consider the use of an alternative energy source, fuel, or technology to extend the operational range of the vehicle while minimizing the logistics footprint required to support it in its missions. This study used this opportunity as an example for which to apply the proposed TMAW, HEMT, and IEM concepts to quantitatively compare several current and emerging alternative energy sources, fuels, and technologies to conventional (petroleum-based) diesel.

B. DEFINING VEHICLE FUEL REQUIREMENTS

To begin the process of applying the techniques of this study to the evaluation of the alternative energy, fuel, and/or technologies solutions as acquisition options for the JLTV fuel source and/or technology, it is first necessary to understand the highest level system requirements for the next-generation tactical wheeled vehicles. In this study, we attempt to use JLTV Program documentation that has captured this information and,

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[2] *Congress Daily*, "Defense Chief to tap Army modernization funds for new vehicle program," 17 April 2009.

[3] Congressional Research Service, *Joint Light Tactical Vehicle (JLTV):Background and Issues for Congress*, 3 August 2009 (RS22942).

where necessary, augment it to consider requirements specifically relevant to energy and fuel consumption.

In FY2006, the Office of Naval Research (ONR) issued a Broad Agency Announcement (ONR BAA Announcement #06-021) for research opportunities in the Conceptual Design & Mockup Science & Technology Efforts in Support of the Family of Joint Light Tactical Vehicles. This BAA provided the following statement:

> In response to an operational need and an aging fleet of light tactical wheeled vehicles, the Joint Services are developing a requirement for a family of new tactical wheeled vehicles. This vehicle will provide increased force protection, survivability, and improved capacity over the current up-armored High Mobility Multi Wheeled Vehicle (HMMWV) while balancing mobility and transportability requirements with total ownership costs.

More specifically, COL John S. Myers (PM Future Tactical Systems), in his Advanced Planning Brief to Industry, stated the minimum desired capabilities of the light tactical wheeled vehicle system platform to be as follows:

- Improved driver, crew protection (direct fire, mines, IED)
- Improved vehicle safety (fire suppression, roll over prevention, etc.)
- Improved weapons mounting provisions
- Improved integration, space, power for C4ISR systems
- Sufficient payload, mobility, while armored and fully loaded
- Improved maintainability, reliability, and fuel efficiency as compared to current systems
- Improved load handling capabilities
- Improved transportability (C-130, CH-47).[4]

Similarly, for the tactical truck system advanced concept:

- Increased survivability & lethality
- Improved fuel efficiency (to include hybrid-electric technologies) & range
- Improved C4ISR
- Increased reliability & simplified maintenance

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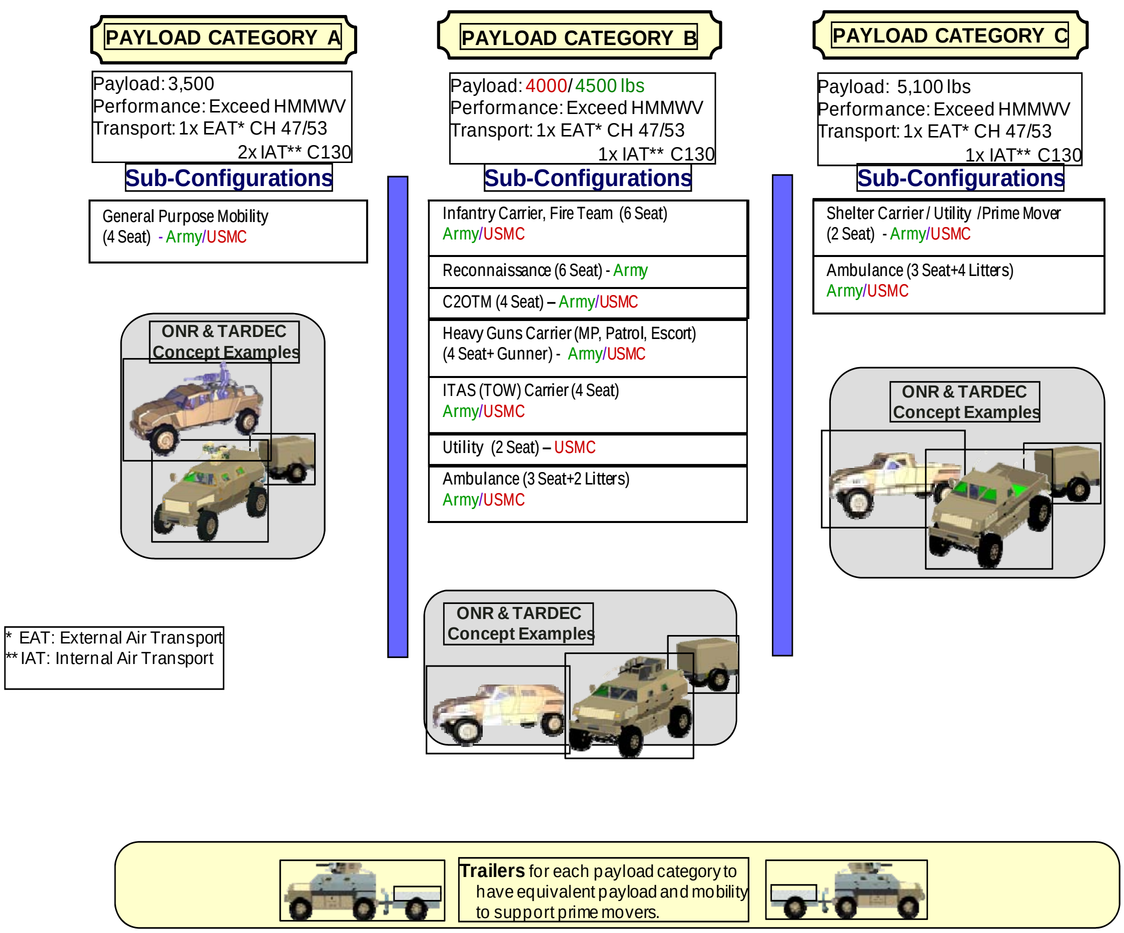
4 COL John S. Myers (PM FTS), *Advanced Planning Brief to Industry*, 27 October 2006.

- Increased deployability; improved cross-country speed
- Improved load-handling capability
- Onboard power and water generation.

This guidance, along with a capabilities gap analysis led to the concept of a JLTV Family of Vehicles and trailers. Figure 18 shows the resulting three categories (A, B, and C) of JLTV vehicles and their respective characteristics. In this study, we will focus on the requirements of Payload Categories A & B as an applied example.



Source: LTC Wolfgang Petermann, *JLTV Information Briefing to Industry*, Pre-proposal Conference, 19-21 Feb 08)

Figure 18. JLTV Family of Vehicles (FOV) Categories

C. APPLYING THE INTEGRATED EVALUATION METHOD (IEM)

This section summarizes the step-by-step application of the TMAW, HEMT, and IEM concepts (described in Chapters II-IV of this report) to compare different alternative energy, fuel, and technologies to a conventional diesel design for the JLTV Category A/B FoVs.

1. Conduct Stakeholder Input (VOC)

As shown in Chapter IV, the first step of the IEM is to conduct the stakeholder input, or voice-of-the-customer. This step includes capturing the JLTV requirements from the JCIDS process, a review of the JLTV concept of operations (CONOPS) as perceived by the end user(s), and the DoD JLTV business (DDR&E, AT&L, CAPE) requirements. In addition, since the goal is to assess the viability of a solution that may employ an alternative energy, fuel, and/or technology (i.e., biodiesel, HEV diesel), the IEM proposes to expand the list of stakeholders to include the requirements imposed by the DESC and the DCMA. This is important since the DESC will need to evaluate its sourcing and logistics capabilities of any new energy or fuel source, which may include large HEV batteries that replace equivalent gallons of fuel.

As stated earlier, this study attempts to use published JLTV information relative to fuel requirements where feasible and augment it with new requirements where applicable. Table 4 summarizes some of the key fuel requirements as obtained from JLTV program documentation with additional requirements added for consideration by this study. It is recognized that these lists are not entirely exhaustive of all captured program requirements but are merely examples of some that have been captured in program briefings and developed for the purposes of this study. See Appendix E for an expanded list.

Table 4. JLTV Stakeholder (VOC) Sample Fuel Requirements

JCIDS (gap analysis & capabilities assessment)[a]	Services Concept of Operations (CONOPS)[a]	OSD Evaluation, Acquisition, & Assessment[a]	Defense Energy Support Center (DESC)	Defense Contract Management Agency (DCMA)
Reduce lines of communication Improve fuel efficiency Extend operational range Better performance Reduced environmental impact	Reduce force protection demands Commonality Adaptable Increases maneuver capacity Provides tactical advantage Operational safety Ease of use Training complexity Logistics and re-supply CONOPS	Cost vs. fixed price contracts (cost per vehicle) Reliability Annual maintenance man hour reduction Fuel efficiency (fully burdened cost of fuel) Life cycle operations & service (O&S) cost reduction	Primary vehicle fuel type Fuel and/or technology sourcing (market competition and availability) Fuel logistics, distribution, and infrastructure support Contracting requirements (short, extended) Commonality with other platforms	Production processes Quality control processes Supplier sourcing Hardware quality control process Software quality control process Traceability Verification and Validation (V&V) procedures

[a] LTC Wolfgang Petermann and LtCol Ruben Garza briefing, *JLTV Information Briefing to Industry*, Pre-proposal Conference (19-21 February 2008).

2. Prioritize Needs and Requirements

The next step in the IEM is to prioritize the needs and requirements identified through the stakeholder VOC into levels of importance. For the JLTV, this study used the Capability Weighting Factors & Level of Importance categories listed in ONR BAA #06-021 as guidance along with a Kano-survey style response sheet (see Appendix E) to rate the requirements in the previous step. Table 5 below shows the weighting factors as published in the ONR BAA.

Table 5. JLTV Capability Weighting Factors and Level of Importance

Factor	Importance
Force Protection & Survivability	45 percent
Mobility	30 percent
Network Enabling & Power Generation	20 percent
Accommodation of Payload	5 percent

It is important to recognize that issues of fuel efficiency or improved logistics lines of communications (LOCs) required for fuel supply lines are not explicitly captured in the above weighting factors. They can, however, be grouped into all categories since an alternative energy, fuel, or technology acquisition option that reduces the need for refueling could lead to improved force protection, extended mobility range, more efficient power generation, and increased payload capability.

One such approach is to further divide the JLTV Capability Weighting factors into conventional (design) requirements and logistics (LOCs) levels of importance. Table 6 shows an example that could be considered for the JLTV. This approach requires that any requirement that would be used to satisfy one of the key capabilities would also be examined for its logistical requirements and is therefore appropriately weighted in the analysis.

Table 6. Augmented JLTV Capability Weighting with Logistics Factors

Factor	Total Weighting	Conventional	Logistics
Force Protection & Survivability	45 percent	30 percent	15 percent
Mobility	30 percent	20 percent	10 percent
Network Enabling & Power Generation	20 percent	15 percent	5 percent
Accommodation of Payload	5 percent	3 percent	2 percent

Table E-1 in Appendix E shows the resulting prioritized fuel needs and requirements based on JLTV system-level requirements.

3. Map Needs and Requirements to Metrics

Having prioritized the stakeholder needs and requirements, the next step in the IEM is to map the needs and requirements to measurable metrics using the HEMT proposed in this study. For the JLTV program, this study also relied on program documentation to augment the measureable metrics as stated in ONR BAA #06-021. Figure 19 shows a partial example of the JLTV fuel HEMT.

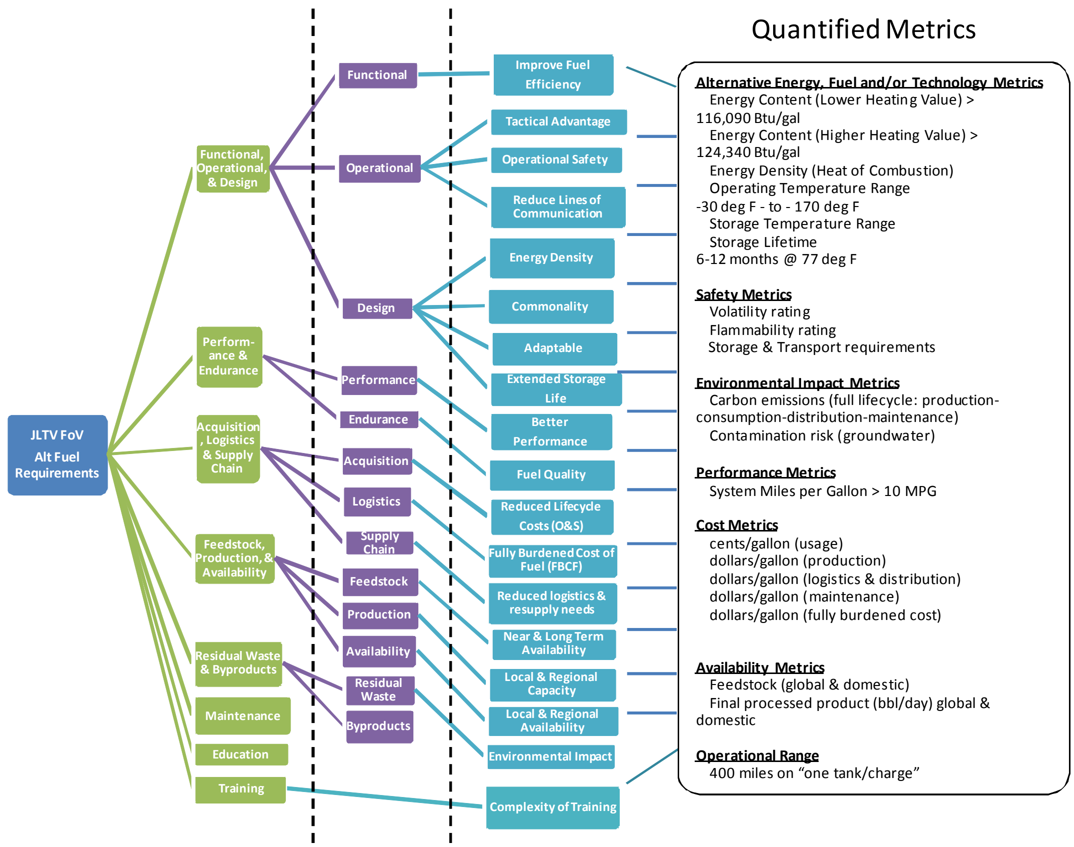


Figure 19. JLTV Alternative Energy, Fuel, and Technology HEMT Example Structure

Note, as stated earlier in this study report, the goal of the HEMT is to decompose the emerging requirements into measurable (quantified) technical metrics. These metrics are then used as a basis for comparison of the competing conventional solutions to those based on an alternative energy, fuel, and/or technology. This decomposition forms the basis of the inter- and intra-technology comparison and is used as input to the House-of-Quality construction as is discussed in the next section.

4. Construct the House-of-Quality (HOQ)

The next step in the IEM is to construct the JLTV alternative energy, fuel, and technology HOQ. This is done by placing the mapped requirements of the HEMT as row entries and the resulting technical metrics as columns in the HOQ, respectively. Current solutions, as well as those based on an alternative energy, fuel, and/or technology, that achieve an acceptable level of maturity based on the TMAW described in Chapater II are then placed as entries in the Planning Matrix ("solutions options"). Figure 20 shows the resulting HOQ, which has been populated for the JLTV alternative energy, fuel, and technology example considered here. For the purposes this study, we limited the HOQ to the top 10 requirements, including those classified as a JUON per the Kano-survey style worksheet in Appendix E.

The following section describes how to interpret the results of the HOQ of Figure 20. It should be pointed out that the JLTV alternative energy, fuel, and technology HOQ of this report is intended to be merely an example and should not be interpreted as a final comparison of the available energy, fuel, and technology options. A more rigorous study is recommended to apply the techniques of this study to a true acquisition study.

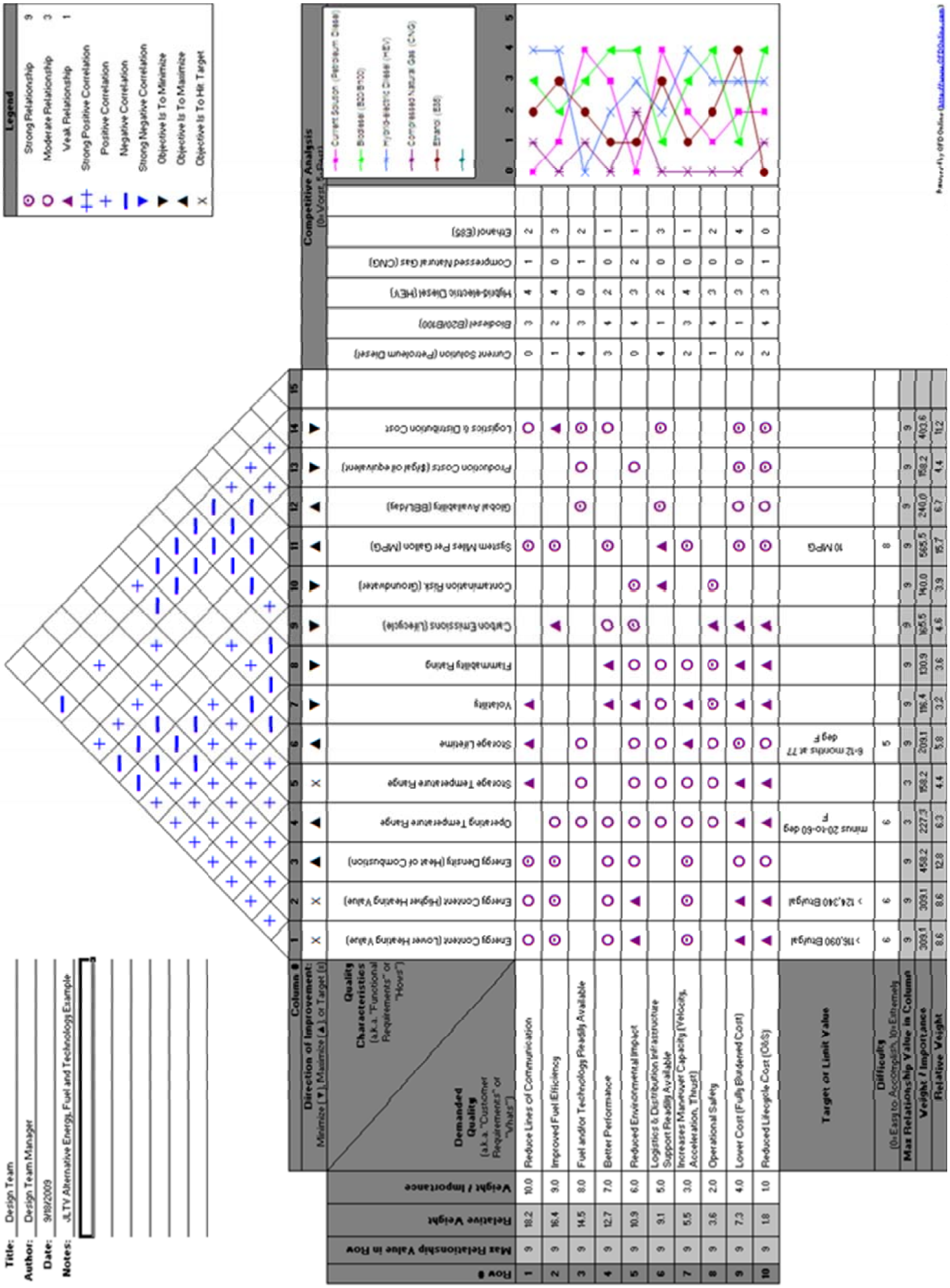


Figure 20. JLTV Alternative Energy, Fuel, and Technology House-of-Quality (HOQ) Example

5. Interpret HOQ Results

Interpreting the results of the HOQ begins by decomposing the HOQ into its constituent components (see Appendix D for a description of the six basic components of the HOQ). From a comparative analysis perspective, the three areas that provide the most helpful insight into the viability of the options being considered are the planning matrix (right side of HOQ), the roof (top of HOQ), and the targets (bottom of HOQ).

The planning matrix provides useful insight into how various alternative energy, fuel, and technology solutions being considered compare against one another given the selected customer requirements (rows of the HOQ). In the JLTV alternative energy, fuel, and technology HOQ example shown in Figure 20, the right side of the HOQ shows the rank order of each solution and its ability to satisfy each of the respective customer product requirements. A graphical representation summarizes the comparison trends of the technologies against one another. In this study's example, it can be seen that on average, the biodiesel solution rated consistently higher, followed by the HEV solution, and the ethanol (E85 flex fuel) option. Petroleum-based diesel (conventional solution) and CNG score consistently lower against all other alternatives when compared against the captured and ranked VOC requirements.

Here it is important to note that the planning matrix allows for inter- and intra-technology comparisons. For example, in the above paragraph we described how the conventional solution (petroleum-based diesel) is compared against the alternative energy, fuel, and technology solutions (biodiesel, HEV, ethanol, CNG). It can be extended to see that all solutions can be directly compared against each other based on their ability to satisfy the customer requirements through this quantitative competitive analysis.

The roof of the JLTV alternative energy, fuel, and technology HOQ provides useful insight into the technical product requirement tradeoffs. As described in Appendix D, the roof of the HOQ shows the correlation between technical requirements. Positive correlation (indicated with a "+") implies that two technical requirements reinforce one another and a negative correlation (indicated with a "-") indicates that satisfying one requirement necessarily means that the other will be more difficult to achieve.

For the JLTV alternative-fuel HOQ example, the roof shows two very significant negative correlation results. Mainly, it is seen that satisfying the energy density and energy content requirements may negatively affect the carbon emission and contamination risk requirements. Similarly, improving the storage lifetime and reducing the volatility, flammability, carbon emissions, and contamination risk of the fuel may negatively affect the production, distribution, and logistics (fully burdened) cost requirements due to additional processing requirements imposed on the feedstock source.

The targets portion of the HOQ shows the relative importance of the technical requirements given the ranked customer requirements. For the JLTV alternative energy, fuel, and technology HOQ example developed in this study, there are three primary fuel technical specifications that emerge as high-priority requirements. Mainly, they are system miles per gallon, energy density, and logistics and distribution cost. This result is to be expected given that the weighted customer requirements as developed by the VOC techniques prioritize the reduced lines of communication and fuel efficiency requirements as the top priorities. Therefore, the system miles per gallon and energy density technical metrics must be fully considered when developing the selected alternative energy, fuel, and/or technology.

In addition, the HOQ target area also identified the logistics and distribution cost technical specification as third highest priority. This is driven by the fact that at least four customer requirements (HOQ row entries) have a strong relationship to this technical metric. Analysis of the JLTV alternative fuel, energy, and technology HOQ shows that customer requirements related to availability of the fuel, logistics and distribution infrastructure support, lower cost (fully burdened) and reduced life cycle costs all have strong relationships to the logistics and distribution cost specification.

A final overall assessment of the HOQ results is recommended to assess the feasibility of the leading solution. Given the results of the HOQ process, the potential for increased carbon emissions due to variations in energy density (carbon-to-hydrogen content) is a result that would be expected. Similarly, increasing the technical performance of an energy source or fuel can result in a negative effect on the total cost (per unit of energy). Both of these results should be considered to assess the feasibility of the resulting solution as a viable acquisition option.

6. Select Key Performance Parameters (KPPs) and Key System Attributes (KSAs)

The next step in the IEM is to identify the KPPs and/or KSAs. The KPPs/KSAs are system requirements that must be satisfied and form the bases of evaluating whether or not the technical solution or solutions from the HOQ are meeting the requirements. Table 7 below shows the KPPs/KSAs considered for the JLTV per program briefings.

Table 7. Example JLTV KPP/KSA[a]

KPP / KSA	Allocated Technology Category	Expected TRL vs CDD Metric @ MS A / MS B	Expected Pacing Metric (If available)	Basis/ Rationale for Assessment
Mobility	Suspension-Steering Power Package-Drive Train	7 / 7	Greater or equal to NRMM X-country performance	ACTD UV Demonstrators (Int'l & LM) JLTV CTV Demonstrator (NATC) JLTV Industry Designs JLTV Evaluation of Alternatives Hybrid Electric Vehicle Experimentation & Assessment (HEVEA)
	Electrical Power	7 / 7		
	HVAC	7 / 7		
Transportability	Direct Fire Armor	7 / 7	Rotary Wing transport MPF ship transport	ACTD UV Demonstrators (Int'l & LM) JLTV CTV Demonstrator (NATC) JLTV Industry Designs JLTV Evaluation of Alternatives
	Underbody Armor	5 / 7		
	Adjustable Height Suspension	6 / 7		
Net-Ready	C4 Suite	7 / 7	Voice Comms, Data Comms, Computing Asset & Software	ACTD UV Demonstrators (Int'l & LM) JLTV CTV Demonstrator (NATC)
	Electrical Energy Storage	7 / 7		
Force Protection	Direct Fire Armor	7 / 7	Exceed UAH in all threat domains	ACTD UV Demonstrators (Int'l & LM) JLTV CTV Demonstrator TWVS ATO (P)
	Underbody Armor	5 / 7		
Survivability	Hull-Frame	7 / 7	Crush Resistant Roof@150% GVW	ACTD UV Demonstrators (Int'l & LM) JLTV CTV Demonstrator TWVS ATO (P)
	Body-Cab	7 / 7		
Payload	Suspension	7 / 7	Varies by Payload Category – 3500 to 5100 lbs	ACTD UV Demonstrators (Int'l & LM) JLTV CTV Demonstrator Gov't Eval of Alternative Concepts JLTV Industry Designs
	Hull -Frame	7 / 7		
Availability (Reliability)	*All major systems / sub-systems*	--- / 7	Point Estimate based on TD Reliability test miles	JLTV CTV Demonstrator

[a] LTC Wolfgang Petermann and LtCol Ruben Garza briefing, *JLTV Information Briefing to Industry*, Pre-proposal Conference (19-21 February 2008).

It is interesting to note that the KPPs and KSAs of Table 7 do not include any parameters that directly consider the fuel properties and/or logistics requirements. In order to directly compare an alternative energy, fuel, and/or technology as a viable acquisition option, this study recommends adding KPPs/KSAs that consider these as key performance metrics. For example, the fully burdened cost of fuel and fuel distribution support can be included in a logistics or energy KPP/KSA. A recommended example might be like that of Table 8.

Table 8. Example Energy and Logistcs KPPs/KSAs

KPP/KSA	Allocated Technology Category
Logistics	Distribution
	Infrastructure
Energy	Availability
	Fully Burdened Cost of Fuel

Similarly, KPPs/KSAs can be selected that specifically address the performance of the alternative energy, fuel, and technology solution selected by the HOQ process. In this example, the biodiesel and HEV-diesel options were the two leading candidate fuel and technology solutions. Based on the HOQ scoring, example KPPs/KSAs specific to the alternative energy, fuel, and technology selected can include *system miles per gallon*, *cost per gallon (fully burdened)*, *availability*, and *carbon emission rate (full life cycle)*.

7. Identify CTQ, CTS, and CTC Metrics

The CTQ, CTS, and CTC metrics measure the view and expectation of the selected solution (from the HOQ process) to satisfy the stakeholder needs and expectations. These parameters differ from the KPPs/KSAs in that they are related to the customer needs and view of the product versus the system technical solution. For the JLTV alternative energy, fuel, and technology example considered in this study, the "Voices" listed in the Kano-survey in Appendix E serve as an input source to selecting the appropriate CTQ, CTS, and CTC parameters. Table 9 below shows a representative example.

Table 9. JLTV CTQ, CTS, and CTC Example Metrics

CTQ	CTS	CTC
Reduced lines of communication	Ease of use	Reduced lifecycle costs
Improves tactical advantage	Complexity of training	Lower cost per gallon (oil equivalent)
Reduces environmental emissions	Operational safety	Increased commonality

8. Monitor and Control

The final step in the IEM is to identify and document how the selected solution will be continuously monitored and controlled to ensure that the resulting product continues to meet customer requirements, KPPs/KSAs, and CTQ/CTS/CTC metrics. As stated in Chapter III, this study recommends using the techniques described in the Six Sigma DMAIC process (see Appendix D for a description of the Six Sigma DMAIC).

Using DMAIC, the baseline performance metrics involved in the development and the delivery of the resulting JLTV alternative energy, fuel, and technology solution are documented at an early phase of delivery. Based on metric satisfaction, improvement parameters and techniques can be identified and used to improve the JLTV solution. This analysis is repeated throughout the cycle from the production of the JLTV solution to the performance of newly deployed units in the field. Deviations from expected performance or areas of improvement identified in practice are captured, and improvement projects are initiated to appropriately address the deficiencies.

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VI. COMMERCIAL INVESTMENT ASSESSMENT

As stated earlier in this report, the ARRA 2009 provided additional Government funding for investment in renewable energy projects. While these funds have provided a starting point for many domestic alternative energy, fuel, and technology efforts, it is important to recognize that, in many instances, Government investment alone cannot help establish a viable commercial market for such energy sources, fuels, and technologies.[1] Other questions regarding supply chain cost and risk, adequacy of maintenance resources and serviceability, and availability and reliability of delivery infrastructure still remain.

A. PRIVATE SECTOR INVESTMENT AND ACADEMIC ACTIVITY IN ENERGY AND FUELS RESEARCH AND DEVELOPMENT

In addition to Government investment, two areas that are investing a significant amount of resources in the development of alternative energy sources, fuels, and technologies are private industry and academia. Invested resources have not been limited to monetary investment, but to the number of capital projects and personnel resources allocated to developing alternative energy sources, fuels, and technologies that affect fixed infrastructure, vehicle (ground, air, maritime), and portable-power energy consumption.

In 2008, total worldwide investment in renewable energy was estimated at $120 billion (USD).[2] The United States became the leader primarily through increased investments in increased ethanol production and wind-power installations. According to the Renewable Energy Policy Network for the 21st Century (REN21), the United States added approximately $24 billion (USD), or 20 percent, of total global new renewable energy investment in 2008. This placed it ahead of Spain, China, Germany, and Brazil in total renewable energy spending, respectively.[3]

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1 JASONS, *Reducing DoD Fossil-Fuel Dependence*, September 2006 (JSR-06-135).

2 REN21, *Renewables Global Status Report 2009 Update.*

3 Ibid.

In addition, 2008 also saw continued growth in private investment in the renewable energy sector. A global total of $15 billion (USD) was spent in research and development projects, which were complemented by an additional investment of $13.5 billion (USD) from private equity sources such as private equity funds and venture capital.[4] Despite the economic downturn of late 2008, banks have also continued to fund large alternative energy, fuel, and technology projects domestically and internationally. Figure 21 summarizes the total global investment in renewable energy since 2004.

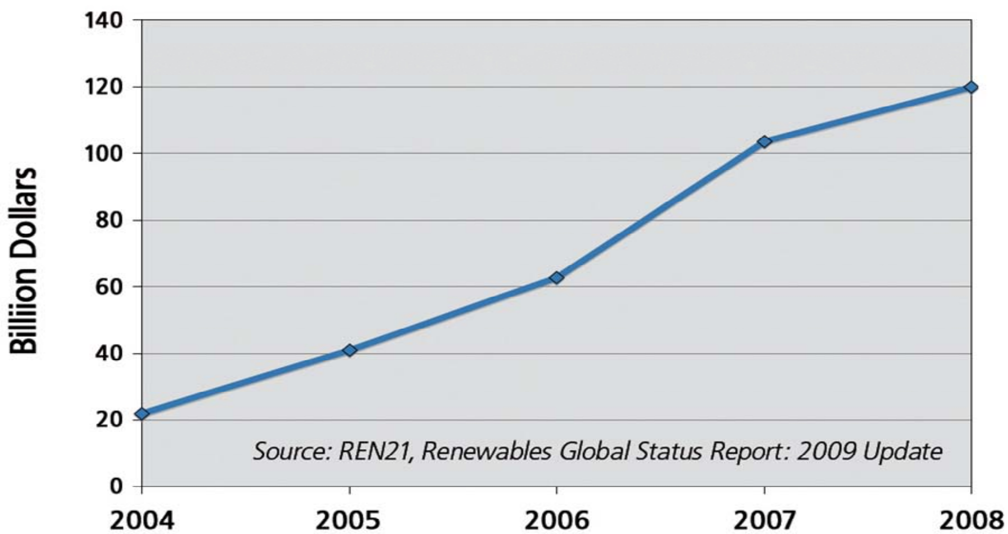

Figure 21. Global Investment in Renewable Energy (2004-2008)

Academic activity has long been the source of continued advances in alternative energy, fuel, and technology. Many top universities have announced the creation of "energy institutes" on their campuses to bring together researchers from cross-functional

[4] Ibid.

disciplines to study renewable energy sources and technologies. One such example is Stanford University's $100 million (USD) investment in the creation of the new Precourt Institute for Energy, which will focus entirely on energy issues.[5] In addition, the U.S. DoE continues to fund the Basic Energy Sciences Advisory Committee composed of experts from top-tier university programs and the DoE national laboratories to examine the "enabling role of basic science" in creating "breakthrough" energy technologies.[6]

B. SUPPLY CHAIN COST AND RISK REDUCTION

Introduction of any alternative energy, fuel, and/or technology into the commercial marketplace and the DoD necessarily brings with it a requirement for significant investment in establishing cost-effective supply-chain routes while reducing inherent risks. The TMAW described in Chapter II related various product phases including production, consumption, distribution, maintenance, and process/technology improvement. Each of these phases would require significant investment to replace or modify the current energy supply chains founded on petroleum or carbon-based supplies. Some estimates have put this figure at well over $7 trillion (USD) in the next few decades.[7]

Performing a complete supply chain cost assessment and risk reduction for each of the alternative energy, fuel, and technologies considered here is beyond the scope of this study. However, such a topic can be the subject of subsequent studies and analyses.

C. ADEQUACY OF MAINTENANCE RESOURCES AND SERVICEABILITY

As more alternative energy, fuel, and technology solutions make their way from the research and development level and into established (or newly created) supply chains, another issue of concern is the adequacy of maintenance resources and serviceability. As with any new product or technology, the skill level and understanding of maintenance personnel and service centers to effectively service, for example, a hybrid-electric or biofuel diesel vehicle may not be adequate. Furthermore, specialized maintenance

[5] Stanford Report, *Stanford launches $100 million initiative to tackle energy issues*, 12 January 2009.

[6] U.S. DoE, *New Science for a Secure and Sustainable Energy Future*, A Report from the Basic Energy Sciences Advisory Committee, December 2008.

[7] Douglas Arent et al., *Alternative Transportation Fuels and Technologies*, Center for Strategic & International Studies (CSIS), August 2009.

centers may be required to service products powered by an alternative energy, fuel, or technology. This may lead to increased life cycle costs and delays in service repairs.

D. AVAILABILITY AND RELIABILITY OF DELIVERY SUPPORT INFRASTRUCTURE

One final consideration in assessing the opportunity for commercial and DoD penetration of an alternative energy, fuel, or technology is the availability of the fuel and reliability of the delivery support infrastructure. To gain large market acceptance, consumers and DoD logisticians typically prefer local availability for energy and fuel sources. Additional costs associated with long delivery infrastructure or having to travel long distances to refuel can be significant limiting factors in the adoption of any selected alternative energy, fuel, and/or technology.

In 2008, the DoE listed a total of 5,756 alternative fueling stations, down from a peak of 7,269 in 1998.[8] The primary drop in the total number of stations was driven by reductions in compressed natural gas (CNG) and liquefied petroleum gas (LPG) fueling stations. However, this was countered by a significant increase in E85 stations that increased in number from 40 in 1998 to 1,644 in 2008. Similarly, gains in biodiesel fueling stations increased from zero in 1998 to 645 in 2008. Figure 22 shows the number of U.S. alternative fueling stations by fuel type from 1992-2008.

While these trends can lead to the conclusion of market trends for alternative vehicle fuel types, assessing domestic alternative fuel market trends is not within the scope of this study and is recommended as a possible follow-on study. In addition, the availability of alternative fuels on the global market should also be studied because of limits in overseas production and distribution of renewable energy sources, fuels, and technologies.

8 DoE-AFDC, *U.S. Alternative Fueling Stations by Type*, 4 December 2008.

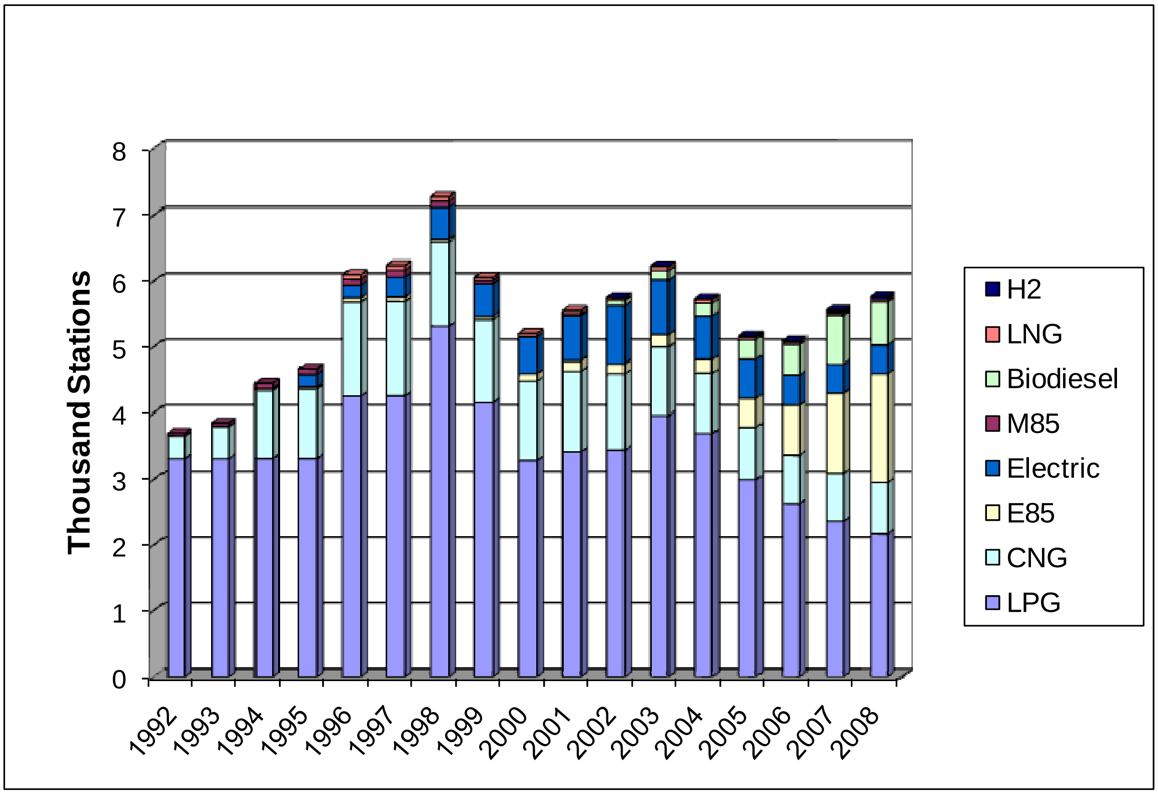

Figure 22. Number of U.S. Alternative Fueling Stations by Fuel Type (1992-2008)

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VII. COMPETITIVE LANDSCAPE

The competitive landscape for alternative energy, fuel, and technology (renewable energy) companies is of significant importance in ensuring continued adequate supplies of the renewable energy source along with constant technical innovation. The viability, reliability, and quality of any renewable-energy supply chain is, in many ways, directly tied to the number of companies that are responsible for producing and investing in the alternative energy, fuel, or technology. From the DoD perspective, the viability of integrating an alternative energy, fuel, or technology into military systems, logistics, and operations is also directly tied to ongoing R&D efforts at primary DoD R&D centers. This section provides a cursory look at the number of renewable energy private businesses and discusses some of the more visible DoD efforts.

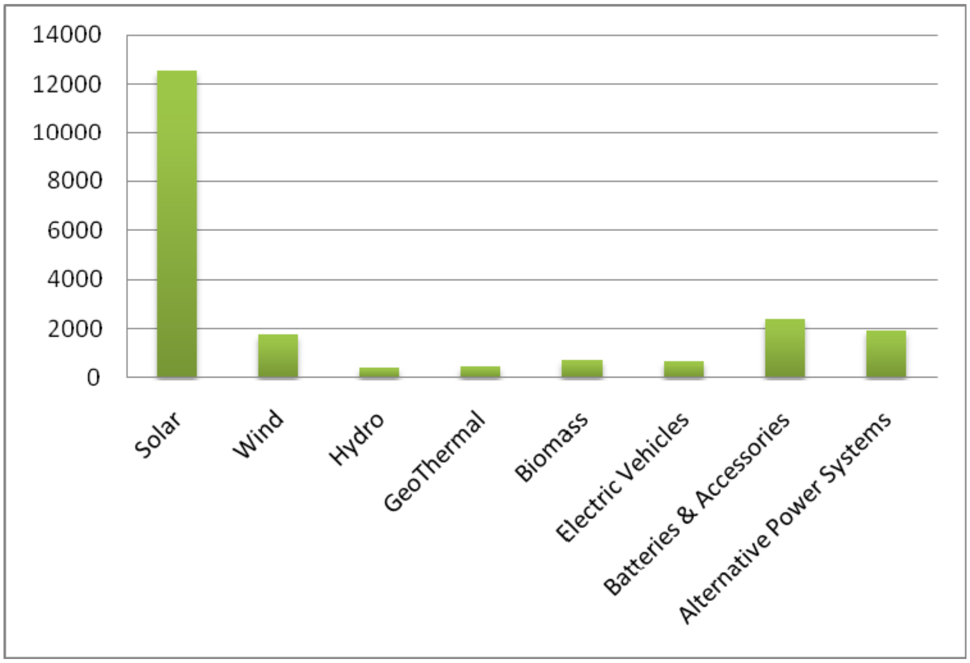
A. DEVELOPERS AND SUPPLIERS OF ALTERNATIVE ENERGY, FUEL, AND TECHNOLOGIES

Due to the exorbitantly high price of a barrel of crude oil experienced in the summer of 2008, expected Government caps on carbon emissions, and a renewed interest in “green projects/jobs,” a significant number of emerging businesses have focused on development of renewable energy sources, fuels, and technologies. In August 2008 more than 160 publicly traded companies were focused on renewable energy and had a total market capitalization of over $240 billion (USD).[1] The primary sectors responsible for this significant market asset valuation came from fixed infrastructure solar/photovoltaic (PV) and wind energy companies and ethanol vehicle fuel producers.

Figure 23 shows a representative number of the renewable energy companies by sector. It can be seen in Figure 23 that the number of solar companies far outpaces those of other renewable energy industries. However, a significant interest in producing biofuels for vehicles has led to the emergence of a large number of bioenergy companies

[1] Eric Martinot & Janet Sawin, *Renewables Global Status Report 2009 Update*, RenewableEnergyWorld.com, 9 September 2009.

that are focused on converting cellulosic- or algae-based feedstocks into a bioethanol liquid fuel. Appendix F lists a representative sampling of leading alternative energy, fuel, and technology companies by the energy consuming sectors considered in this study.



Source: Posharp.com

Figure 23. Number of Companies by Renewable Energy Sector

While an in-depth analysis of the capabilities, processes, and technologies of the private sector renewable energy companies is of extreme value, this study focused on developing the evaluation metrics and methodology that can be used to assess the available and emerging renewable energy sources and technologies. However, it is highly recommended that such private industry capabilities analyses be considered in future studies and used as input to the metrics and methods proposed as a part of this study.

B. DOD RESEARCH AND DEVELOPMENT (R&D) EFFORTS

In addition to the solutions offered by the renewable-energy private businesses, the integration of alternative energy sources, fuels, and technologies into military systems, logistics, and operations will be driven and motivated by DoD investment in renewable energy and efficiency R&D projects. Such projects can be found within many of the DoD research centers and support facilities. This section summarizes some of the more extensive efforts encountered during this study.

The U.S. Army Research, Development, and Engineering Command (RDECOM) along with its Tank-Automotive Research, Development and Engineering Center (TARDEC) are leading some of the Army's early evaluation and adoption efforts of alternative energy sources, fuels, and technologies for vehicle use. In FY 2007, there were more than 130 active power and energy projects at TARDEC.[2] The bulk of the ground vehicle projects focused on prime power sources, non-primary power, energy storage, and power and thermal management. In addition, advanced fuel validation projects are also being undertaken. A notable example is the Fuel Efficient Ground Vehicle Demonstrator (FED) effort, which established a Government-led collaborative effort with industry and subject matter experts to brainstorm and evaluate technologies that increase light tactical vehicle fuel efficiency.[3] In a parallel effort, TARDEC's Fuel and Lubricant Research facility operated by the Southwest Research Institute is also leading efforts in synthetic jet fuels, biodiesel fuel, and hydrogen technology.[4]

In response to potential threats on the electrical grid and given the vast amount of land occupied by domestic installations, the U.S. Army is also investing in several initiatives that integrate renewable energy sources as viable supply sources. As of late 2007, there were 12 geothermal heat pump installations, 13 solar/photovoltaic installations, three wind-generation installations, four solar hot-water installations, and one each hydropower and biomass installations.[5] More recently, the Army has announced major initiatives in solar power-generation opportunities at Fort Irwin, CA, through its Enhanced Use Lease (EUL) program.[6]

The U.S. Navy Office of Naval Research (ONR) is also conducting studies in efficient power and energy technology. Efforts have been focused on energy storage,

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2 Ms. Jennifer Hitchcock (Assoc. Director Ground Vehicle Power and Mobility – TARDEC), *Power and Energy Strategy*, 3 August 2007.

3 Fuel Efficient Ground Vehicle Demonstrator (FED), http://www.peogcs.army.mil/FED/default.aspx

4 TARDEC Fuels and Lubricants Research Facility, http://www.swri.org/4org/d08/TARDEC/default.htm.

5 Mr. Andy Valentine (Asst for Engineering Mgmt – ODASA I&H), *Army Installation Renewable Energy Program*, 13 June 2007.

6 US Army, http://eul.army.mil/ftirwin.

power electronics, power generation, and alternative energy sources. A notable example is the Naval Research Laboratory's (NRL) contract award to Protonex for the advanced development of high-power fuel cells for small unmanned aerial systems (UAS).[7] This effort seeks to extend the power capability of the UAS fuel-cell technology to enable significant platform operational capability improvements. In addition, the Navy also recently announced the purchase of 40,000 gallons of camalina-based jet biofuel to be delivered for testing to the Naval Air Systems Command (NAVAIR) fuels team.[8] Camalina-based jet fuel is made from camalina plants and has been shown to reduce carbon emissions by 80 percent when compared to petroleum-based aviation jet fuel.

As mentioned previously in this report, the U.S. Air Force has completed a series of flight tests using a 50/50 synthetic fuel blend on a B-52 Stratofortress, a C-17 Globemaster III, and the B-1B Bomber. The synthetic fuel blend was created using a Fischer-Tropsch (FT) process, resulting in a cleaner burning and more cost-effective jet fuel.

The Defense Advanced Research Projects Agency (DARPA) is also investing in alternative energy, fuel, and technology research. Some examples of notable projects at DARPA's Defense Sciences Office (DSO) include the Mobile Integrated Sustainable Energy Recovery (MISER) and the Robust Portable Power programs.[9] The MISER program seeks to convert the energy content of plastic packaging material used on remote bases into useable electricity; the Robust Portable Power program seeks to reduce the number of primary batteries in use by replacing soldier-carried batteries with portable fuel cells and unmanned aerial vehicle packs with Stirling engine generators. In addition, the Strategic Technology Office (STO) has invested in development of a very high-efficiency solar cell capable of achieving an efficiency factor greater than or equal to 40 percent while keeping the module manufacturing cost under $1,500 (USD).[10]

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7 Protonex.com, *Protonex receives $598,813 to extend capabilities of unmanned aerial vehicle propulsion systems*, 17 September 2009.

8 Susoil.com, *Sustainable Oils to Supply Navy with Camalina-based Jet Fuel*, 9 September 2009.

9 DARPA, http://www.darpa.mil/dso/thrusts/physci/index.html.

10 DARPA, http://www.darpa.mil/STO/smallunitops/vhesc.html.

VIII. CONCLUSIONS

Alternative energy sources, fuels, and technologies (renewable energy) are continuing to evolve and grow into viable options that address the current dependence on petroleum-based products. Significant improvements in renewable energy technologies for fixed infrastructure, vehicles, and portable power have been made through continued Government and private investment in research and development. The ARRA 2009, passed into law in February of 2009, makes continued investments in energy-related research and infrastructure improvements that may, in time, result in the widespread commercial and DoD adoption of renewable energy technologies. Fixed infrastructure projects in solar, wind, geothermal, and biomass energy production are continuing to improve efficiency performance levels that make it more cost-competitive with current coal and natural gas facilities. Vehicle fuels such as biodiesel (e.g. cellulosic- or algae-based) and vehicle drive technologies (e.g., hybrid-electric) are also evolving through continued developmental focus and emphasis. Fuel cells and battery technologies continue to improve the lifetime of portable power packs enabling longer use of portable electronic devices while still maintaining low size and weight.

To date, many of the alternative energy sources, fuels, and technologies have not enjoyed significant market penetration because of their unavailability or higher cost when compared to the current petroleum-based options. Unresolved issues of feedstock availability, production process definitions, consumption, and distribution still remain. Also, the effects imposed on the environment throughout the lifecycle of a renewable energy technology, from production to distribution, still remain largely unknown or not fully analyzed.

Adequately assessing an alternative energy source, fuel, or technology as a viable DoD acquisition option requires an assessment process that looks beyond just the cost per gallon or per kilowatt. It requires an understanding of common metrics and an integrated evaluation method that can systematically evaluate an energy source, fuel, or technology from feedstock source to full system integration and deployment. This study report describes the Technology Maturity Assessment Wheel (TMAW), Hierarchical Evaluation

Metrics Tree (HEMT), and the Integrated Evaluation Method (IEM) that enable the quantitative comparison and evaluation of alternative energy sources, fuels, and technologies for commercial and DoD applications.

Appendix A

ALTERNATIVE ENERGY, FUELS, AND TECHNOLOGIES SURVEY SUMMARY

Appendix A
ALTERNATIVE ENERGY, FUELS, AND TECHNOLOGIES SURVEY SUMMARY

Type	Primary Current Fuel Supply Source	Existing Alternative Source	Emerging Alternative Supply Source
Fixed Infrastructure	Petroleum, Coal, Natural Gas	Hydroelectric, Solar/PV, Wind, Nuclear	Biomass, Biofuel, Waste, Wood Derived Fuels, Geothermal
Vehicle Fuels, Hybrid, and Alternative Technologies			
Ground	Petroleum-Based Gasoline	Natural Gas (Compressed, Liquid), Hybrid-electric, Ethanol (E85), Methanol, Propane, Biodiesel, Ultra Low Sulfur Diesel, Electric	Biobutanol, Biogas, Biomass -to-Liquids (BTL), Coal-to-Liquids (CTL), Fischer-Tropsch Diesel, Gas-to-Liquids (GTL), Hydrogenation Derived Renewable Diesel (HDRD), P-Series, Compressed Air-Hybrid, Solar
Air	Petroleum-Based JetA/A1, JP-8	None	Synthetic Blend, Biofuel (Algae)
Maritime	Petroleum-Based Marine Bunker	Nuclear (military)	Synthetic Blend, All Electric Drive
Portable Power and Battery Technologies			
Batteries	Alkaline, Sealed Lead Acid, Nickel-Metal Hydride, Lithium-Ion, Lithium-Polymer	None	Fuel Cells, Solar, Radio Frequency
Portable Power (Generators)	Petroleum-Based Gasoline	Electric, Solar (low power)	Fuel Cells, Biofuel, Waste, Nuclear

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Appendix B

TECHNOLOGY MATURITY ASSESSMENT (TMA) TECHNICAL READINESS LEVEL (TRL) DATASHEET

Appendix B
TECHNOLOGY MATURITY ASSESSMENT (TMA) TECHNICAL READINESS LEVEL (TRL) DATASHEET

Table B-1. Fixed Infrastructure TMAW Scoring

Fuel Type	Production	Consumption	Distribution	Maintenance	Process/ Technology Improvement	Average
Petroleum	5	2	5	5	3	4
Coal	5	3	4	4	3	3.8
Natural Gas	4	3	4	3	3	3.4
Hydroelectric	5	3	4	4	3	3.8
Solar/PV	4	3	4	4	3	3.6
Wind	4	3	3	3	4	3.4
Nuclear	4	3	3	2	3	3
Biomass	3	2	2	2	2	2.2
Biofuel	2	2	1	2	2	1.8
Waste	3	2	2	2	2	2.2
Wood-Derived Fuels	2	2	2	2	2	2
Geothermal	3	3	3	3	2	2.8

Table B-2. Existing Vehicle Fuel TMAW Scoring

Fuel Type	Production	Consumption	Distribution	Maintenance	Process/ Technology Improvement	Average
Petroleum	5	4	5	5	3	4.4
CNG/LNG	4	3	4	5	4	4
Hybrid-Electric	4	4	4	4	4	4
E85	4	4	3	4	4	3.8
Methanol	3	4	3	3	3	3.2
Propane	4	4	3	4	3	3.6
Biodiesel	4	4	3	3	4	3.6
Low Sulfur Diesel	4	4	4	3	4	3.8
Electric	2	2	2	2	3	2.2

Table B-3. Emerging Alternative Vehicle Fuels TMAW Scoring

Fuel Type	Production	Consumption	Distribution	Maintenance	Process/ Technology Improvement	Average
Biobutanol	2	1	1	1	2	1.4
Biogas	2	2	1	2	2	1.8
Biomass-to-Liquids (BTL)	2	2	2	2	2	2
Coal-to-Liquids (CTL)	2	2	1	2	2	1.8
Fischer-Tropsch Diesel	3	2	2	2	3	2.4
Gas-to-Liquids (GTL)	2	2	1	2	2	1.8
HDRD	2	1	1	2	2	1.6
P-Series	1	1	1	1	2	1.2
Compressed-Air Hybrid	2	1	2	2	2	1.8
Solar	2	2	1	2	2	1.8

Table B-4. Air and Marine Fuel TMAW Scoring

Fuel Type	Production	Consumption	Distribution	Maintenance	Process/ Technology Improvement	Average
Petroleum (JetA-JP-8)	4	4	5	4	4	4.2
Air – Synthetic Blend	4	2	2	3	4	3
Air – Biofuel	2	2	2	2	3	2.2
Petroleum – Marine Bunker	4	4	5	4	4	4.2
Marine – Synthetic Blend	2	2	2	2	2	2
Marine – All Electric	4	2	2	3	4	3

Table B-5. Battery Technology TMAW Scoring

Fuel Type	Production	Consumption	Distribution	Maintenance	Process/ Technology Improvement	Average
Alkaline	5	5	5	4	4	4.6
Sealed Lead Acid	5	5	5	3	3	4.2
Nickel-Metal Hydride	4	4	5	4	4	4.2
Lithium-Ion	4	4	5	3	4	4
Lithium-Polymer	4	4	5	4	4	4.2
Fuel Cells	4	3	2	3	4	3.2
Solar	3	3	2	3	4	3
Radio Frequency	2	1	1	2	3	1.8

Table B-6. Portable Generator Technology TMAW Scoring

	Production	Consumption	Distribution	Maintenance	Process/ Technology Improvement	Average
Petroleum Fuel	5	5	5	4	4	4.6
Electric	4	3	3	4	4	3.6
Solar	3	2	2	3	4	2.8
Fuel Cells	3	2	2	2	3	2.4
Biofuel	2	2	2	2	3	2.2
Waste	2	2	2	2	3	2.2
Nuclear	3	2	2	1	3	2.2

Appendix C

EXAMPLE METRICS SUMMARY TABLE

Appendix C
EXAMPLE METRICS SUMMARY TABLE

Table C-1. Sample Hierarchical Evaluation Metrics Tree (HEMT)

Metric Class Type	Metric Areas	Fixed Infrastructure	Vehicle Fuels			Portable Power	
			Ground	Air	Marine	Batteries	Generators
Functional, Operational & Design	Functional	Btu generating capacity	Survivability	Survivability	Survivability	Form factor	Survivability
	Operational	Efficiency	Expeditionary	Long range, Detectability	Long range	Long life, rechargeable	Portability
	Design	kilowatt/acre	Mass, Weight, Volume	Mass, Weight, Volume	Mass, Weight, Volume	Energy density, Weight, Volume	Mass, Weight, Volume
Performance & Endurance	Performance	All weather, Reliability	All terrain, Reliability	Altitude, Speed, Reliability	Deep water, Green water, Speed	Fast recharge	All weather
	Endurance	Expected service lifetime	Expected service lifetime	Expected service lifetime	Expected service lifetime	Low and high temperature operation	Expected service lifetime
Acquisition, Logistics, & Supply Chain	Acquisition	Fully burdened cost of adoption (FBCA)	Fully burdened cost of fuel (FBCF)	Fully burdened cost of fuel (FBCF)	Fully burdened cost of fuel (FBCF)	Cost/amp hour	Fully burdened cost of fuel (FBCF)
	Logistics	Available infra-structure	Transport-ability	In-air refueling capability	Strategic port locations	Transport-ability	Transport-ability
	Supply Chain	Fuel distribution require-ments	Fuel distribution requirements	Fuel distribution requirements	Fuel distribution requirements	Market availability	Fuel distribution requirements

Table C-1. Sample Hierarchical Evaluation Metrics Tree (HEMT) (Continued)

Feedstock, Production, & Availability	Feedstock	Source inventories & risk	Source inventories & risk	Source inventories & risk	Source inventories & risk	Source inventories & risk	Source inventories & risk
	Production	Capacity	Capacity	Conversion capacity	Conversion capacity	Capacity	Capacity
	Availability	Global availability	Regional availability	Global availability	Global availability	Global availability	Regional availability
Residual Waste & Byproducts	Residual Waste	Emissions	Emissions	Emissions	Emissions	Outgassing	Emissions
	Byproducts	Process emissions	Process emissions	Process emissions	Process emissions	Process emissions	Process emissions
Maintenance	Maintenance	Service cycle	Service cycle	Service cycle	Service cycle	Service cycle	Service cycle
Education	Education	R&D investment	R&D investment	R&D investment	R&D investment	R&D investment	R&D investment
Training	Training	Maintenance procedures	Maintenance procedures	Maintenance procedures	Maintenance procedures	Maintenance procedures	Maintenance procedures

Appendix D

QUALITY FUNCTION DEPLOYMENT (QFD) AND SIX SIGMA CONCEPTS

Appendix D
QUALITY FUNCTION DEPLOYMENT (QFD) AND SIX SIGMA CONCEPTS

The IEM proposed in this study is founded upon commonly used and well-known QFD and Six Sigma techniques. In particular, VOC and HOQ concepts and tools are integral to the described method. This appendix provides a summary description of the pertinent QFD and Six Sigma concepts.

A. Quality Function Deployment (QFD)

QFD is an approach to systems thinking that is widely used in today's environment to link the needs of the customer (end user) with design, development, engineering, manufacturing, and service functions.[1] Key components of QFD include:

- Understanding customer requirements (Voice of the Customer)
- Quality systems thinking + psychology + knowledge/epistemology
- Maximizing positive quality that adds value
- Comprehensive quality system for customer satisfaction
- Strategy to stay ahead of the game.

In general, QFD is designed to align the needs and requirements of the customer with business functions and organizational processes.

QFD concepts are well-suited to the objectives of this study, particularly as it relates to evaluating vastly different alternative energy sources, fuels, and technologies for use in military systems, logistics, and operations. Here, the needs and requirements of the DoD end user of an alternative energy source, fuel, or technology (the military Services) must be aligned with the business functions (OSD DDR&E, CAPE, and AT&L) and organizational processes (DESC and DCMA). Hence, it is very appropriate to use such techniques as (Kano surveys) and HOQ.

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[1] Quality Function Deployment Institute – http://www.qfdi.org.

B. KANO SURVEY (MODEL)

The Kano Survey (model) is a VOC tool used to confirm and categorize critical-to-the-customer requirements. It typically classifies customer preferences into five categories including attractive, one-dimensional, must-have, indifferent, and reverse.[2] Kano's model focuses on differentiating product features, as opposed to focusing initially on customer needs. A common representation of the model is to map the results of the Kano surveys onto a four quadrant chart (see Figure D-1 below).

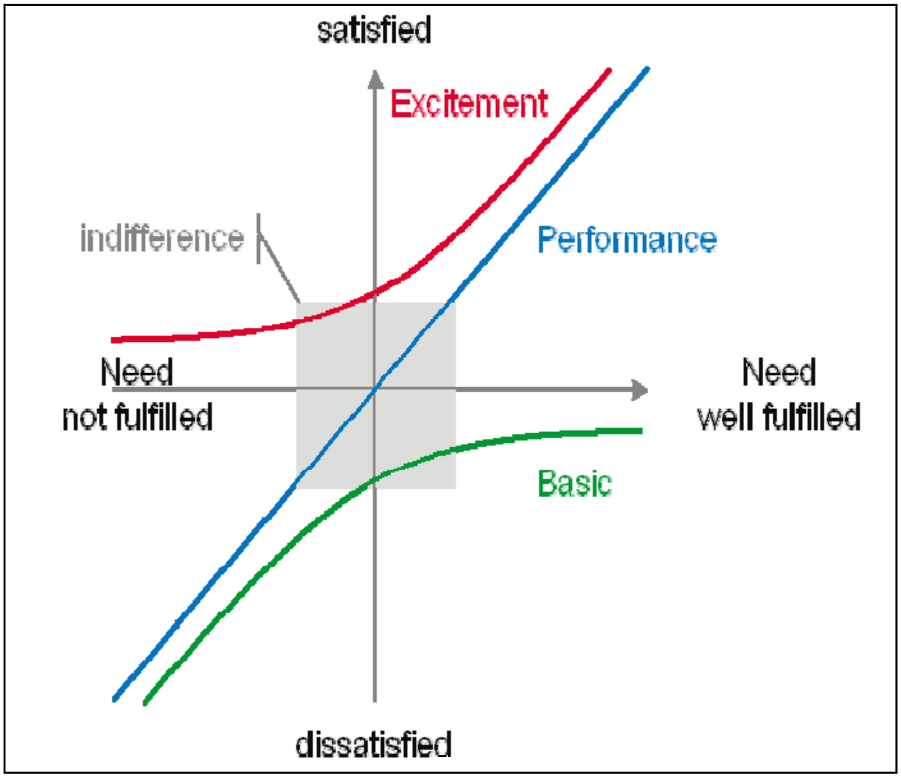

Figure D-1. Kano Model Graph

The three lines of differentiation in the Kano model of Figure D-1 are labeled as basic, performance, and excitement. Customer needs and requirements that fall in the basic area of the chart are those requirements that are expected to be satisfied and, if a selected technology does not meet them, the end result is that the customer will be extremely dissatisfied. Similarly, needs and requirements falling along the performance line are those that the customer expects the selected technology to meet (think of it as the

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2 Wikipedia.org - http://en.wikipedia.org/wiki/Kano_model.

minimum product requires) at a minimum. Finally, the excitement category includes those needs and requirements that the customer views as going above the technology expectations. Requirements falling in the indifferent region can be considered as “nice-to-have,” but not critical to product satisfaction.

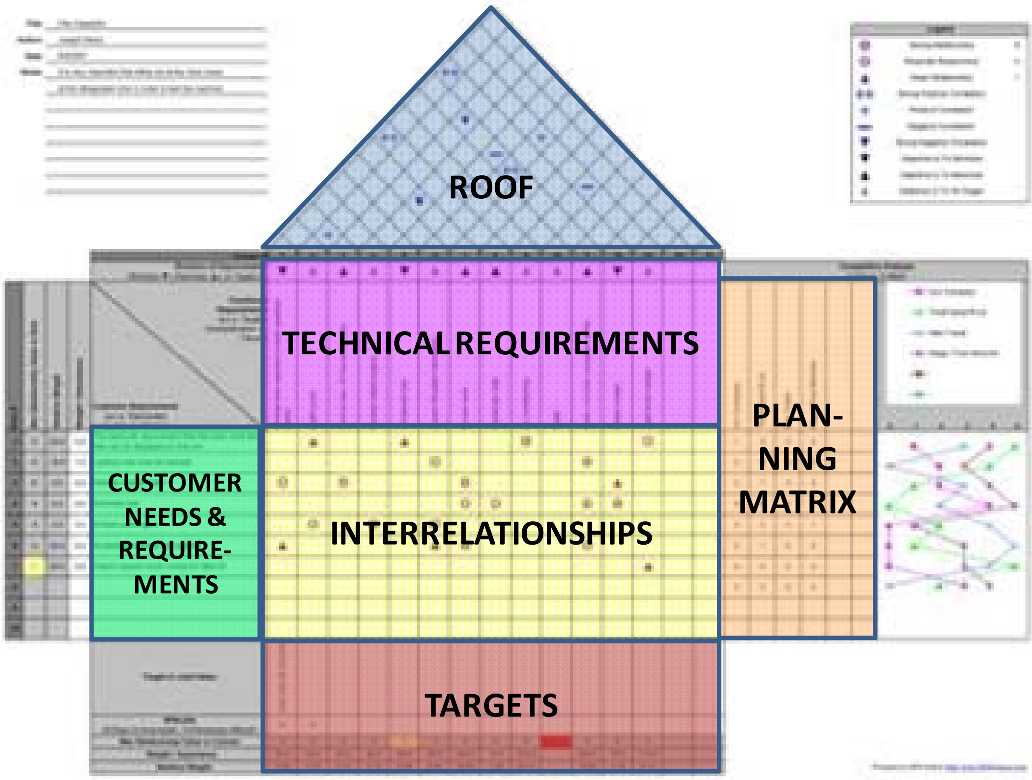
C. QFD HOUSE-OF-QUALITY (HOQ)

An integral part of the IEM proposed in this study is the QFD HOQ. The HOQ is a quantitative approach to comparing customer needs and requirements, typically derived from a VOC activity (i.e., Kano survey), to technical performance and solutions options. It consists of five main components, including customer needs and requirements, planning (competitive analysis) matrix, technical requirements, interrelationships, roof, and targets.[3] Figure D-2 shows an example of the HOQ.

Each of these areas serves a primary role in quantitatively assessing an alternative energy source, fuel, or technology for use in military systems, logistics, and operations. Their respective roles can be summarized as follows:

- Customer Needs and Requirements—Structured list of product’s requirements. In this study, product is used to refer to the alternative energy, fuel, or technology being considered.
- Planning Matrix—Compares the ability of competitive solutions to meet customer needs and requirements as perceived by the customer. In this study, the TMAW is used as input.
- Technical Requirements—Lists measureable characteristics of the alternative energy source, fuel, and technology. In this study, the HEMT is used to derive and populate the requirements columns.
- Interrelationships—Translates the customer needs and requirements to the technical requirements
- Roof—Is used to identify where respective technical requirements support or impede one another. For example, will satisfying one technical requirement come at the expense of another?
- Targets—Quantitatively represents the relative importance of the technical requirements given the ranked customer requirements.

[3] QFD online: http://www.qfdonline.com/templates.



Source: QFDonline.com

Figure D-2. Quality Function Deployment House-of-Quality

Appendix F uses this template as an example applied to military ground vehicles.

D. SIX SIGMA DEFINE, MEASURE, ANALYZE, IMPROVE, AND CONTROL (DMAIC)

The Six Sigma DMAIC process is an improvement system for existing processes falling below specification and looking for incremental improvement.[4] The goal of DMAIC is to ensure that products and processes continue to meet customer needs and requirements through their lifecycle. The purpose of the five techniques can be summarized as follows:

- Define—Improvement activity goals
- Measure—Current system performance

[4] iSixSigma.org - http://www.isixsigma.com/sixsigma/six_sigma.asp.

- Analyze—Gaps between improvement goals and current system performance
- Improve—System performance through change initiatives
- Control—New system performance.

In this study, we apply the DMAIC concepts within the IEM to continuously evaluate the ability of a selected alternative energy source, fuel, or technology to meet the needs of the military end users, OSD business objectives, DESC energy delivery goals, and DCMA quality control requirements.

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Appendix E

INTEGRATED EVALUATION METHOD (IEM) EXAMPLE DATASHEETS

Appendix E
INTEGRATED EVALUATION METHOD (IEM) EXAMPLE DATASHEETS

Table E-1. Kano Survey-Style JLTV Example Alternative Fuel Needs and Requirements Prioritization

Voices	Joint Urgent Need (JUON)	Term	"Must have"	"Like to have"	"Not critical"
Provides tactical advantage		Mid	12		
Reduce lines of communication	1	Short			
Better performance	5	Short			
Improve fuel efficiency	2	Short			
Adaptable		Long		17	
Available fuel and/or technology logistics, distribution, & infrastructure support	7	Short			
Increased maneuver capability		Mid	8		
Increased commonality		Long		16	
Reduced environmental impact	6	Short			
Lower cost (fully burdened cost of fuel)	4	Short			
Ease of use		Mid	11		
Operational safety		Mid	9		
Fuel and/or technology availability	3	Short			

Table E-1. Kano Survey-Style JLTV Example Alternative Fuel Needs and Requirements Prioritization (Continued)

Reduced life cycle costs (O&S)		Mid	10		
Complexity of training		Mid	15		
Extended storage Llfe		Mid	14		
Fuel quality		Mid	13		

Appendix F

COMPETITIVE LANDSCAPE

Appendix F
COMPETITIVE LANDSCAPE

Table F-1. Fixed Infrastructure Renewable Energy Company Listing[a, b]

	Fixed Infrastructure	
Wind:	Solar:	Hydropower, Biomass, Geothermal, Waste:
AAER Systems (Canada)	Aleo Solar (Germany)	Advanced Hydro Solutions (USA)
AeroCity Wind Power (USA)	Anwell Solar (China)	AltaRock Energy (USA)
Aeronautica Wind (USA)	BP Solar (Spain, USA)	Alternative Hydro Solutions (Canada)
Aerostar Wind Turbines (USA)	BrightSource Energy (USA)	Barber-Nichols, Inc. (USA)
Americas Wind Energy, Inc. (Canada) (see also Lagerwey Wind)	China Sunergy (China)	Blue Energy Canada, Inc. (Canada)
Bergey (USA)	Citizenre, (USA)	Calpine Corp. (USA)
ChapDrive (Norway)	ET Solar (China)	Canadian Hydro Power Developers, Inc. (Canada)
Clipper Windpower (USA)	Evergreen Solar (USA)	ChemRec (Sweden)
CWind, Inc. (Canada)	First Solar (USA, Germany)	Chevron (USA)
(Germany/USA) - bought by Daewoo Shipbuilding & Marine Engineering in 2009	GE Energy - Solar Power, (USA)	Enel Green Power (Italy)
Dragonfly Industries, Inc. (USA)	Global Solar (USA)	Enerflo Geothermal Technologies (Canada)
DyoCore, Inc. (USA)	GreenSun Energy (Israel)	GE Energy (USA)
Enertech (USA)	HelioVolt, (USA)	Geodynamics (Australia)
Entegrity Wind Systems (Canada)	International Solar Electric Technology, (USA)	GeoScience, LTD (UK)
General Electric (USA)	Isofotón (Spain)	GeoThermEX, Inc. (USA)
Green Wave (USA)	Konarka Technologies, Inc. (USA)	Geysir Green Energy (Iceland)
Heartland Energy Solutions (USA)	LDK Solar (China)	Magma Energy Corp. (Canada)
HelixWind (USA)	Miasolé (USA)	MidSouth Geothermal (USA)
Jacobs, now Wind Turbine Industries (USA)	Mitsubishi Electric (Japan)	Mitsubishi Power Systems, Inc. (USA)
Liquid Wind (USA)	Moser Baer Photovoltaic (India)	Nevada Geothermal (USA)
Neo-Aerodynamic (USA)	Motech (Taiwan)	Ocean Power Delivery, LTD (Scotland)
Nordic Windpower (USA)	Nanosolar (USA)	Ormat Technologies (Israel, USA)
Northern Power Systems (USA)	Pyron Solar (USA)	PB Power (Australia)
PacWind (USA)	Renewable Energy Corporation (Norway)	Siemens (Germany, USA)
Southwest Windpower (USA)	Schott Glass (Germany)	SkyPower Systems (USA)
WES Canada (Canada/US)	Signet Solar (USA)	
	SkyFuels, Inc. (USA)	
	SolarWorld (Germany)	

[a] Wikipedia.org, *Renewable Energy Industry,* July 2009.

[b] Posharp.com, *Renewable Energy Business Database,* 2009.

Wind Simplicity, Inc. (Canada) Windtec (Austria/US) - subsidiary of American Super Conductor Corporation	Spectrolab, Inc., (USA) Sun Edison (USA) Sungen International Limited (Hong Kong) Sun Power Corp. (USA) Trina Solar (China) WorldWater and Solar Technologies Corp.(USA) Yingli (China)	Sterling Planet (USA) Toshiba Corp (Japan) US Geothermal, Inc. (USA)

Table F-2. Vehicle Alternative Fuel, Hybrid, and Alternative Technologies Company Listings[a,b]

	Vehicle Fuels, Hybrids & Technologies	
Fuels: Abengoa Energy (Spain) Algenol Biofuels (USA) Amyris Biotechnologies (USA, Brazil) Aquaflow Bionomic (New Zealand) Aurora Biofuels (USA) Bionavitas (USA) Bluefire Ethanol Fuels, Inc. (USA) British Petroleum (UK) Cavitation Technologies, Inc. (USA) Ceres, Inc. (USA) ChevronTexaco (USA) Choren (Germany) Cobalt Biofuels (USA) Coskata (USA) Coulomb Technologies (USA) Dupont Danisco (Denmark) Dynamotive (Canada, USA) ETH Bioenergia (Brazil) ExxonMobil (USA) GEM Biofuels (USA) Gevo (USA) GreenFuel Technologies Corp. (USA) Iogen Corp. (Canada) Ineos (USA, UK) KL Energy (USA) Lake Eerie Biofuels (USA) LS9, Inc. (USA) Novozymes (Denmark) Petrobras (Brazil)	Sanimax Energy (Canada) Sapphire Energy (USA) SEKAB (Sweden) Shell (Netherlands) Simple Fuels Biodiesel, Inc. (USA) Smart Fuels, LLC (USA) Solazyme, Inc. (USA) Southeast BioDiesel LLC (USA) Soy Energy, Inc. (USA) Soymor Biodiesel (USA) Standard Biodiesel, Inc. (USA) St1 Biofuels Oy (Finland) Sustainable Oils (USA) Sustainable Power Corp. (USA) Sun Power Biodiesel, LLC (USA) Sunsoil, LLC (USA) Sunx Energy, Inc. (Canada) Synergy Biofuels (USA) Syngenta (Switzerland, USA) Synthetic Genomics (USA) Taurus Energy (Sweden) Tellurian Biodiesel, Inc. (USA) Terra Bioenergy (USA) TMT Biofuels, LLC (USA) Tulsa Biofuels, LLC (USA) United Biofuels, (USA) United Oil Co. (USA) US Alternative Fuels Co. (USA) US Biofuels, Inc. (USA) UOP/Honeywell (USA) Verenium (USA)	Hybrid, Electric, & Alternative Technologies: Honda Motor Co. (Japan, USA) Aptera Motors (USA) BAE Systems (USA) Caterpillar (USA) Chevrolet (USA) Cummins Engine Co. (USA) DaimlerChrysler, LLC (Germany, USA) Detroit Diesel (USA) Eaton (USA) Enova Systems (USA) Fiat (Italy) Fisker Automotive, Inc. (USA) Ford Motor Co. (USA) General Motors Corp. (USA) Global Electric Motorcars (USA) Green Vehicles (USA) Hitachi Mining (Japan) Honeywell (USA) International (USA) Lightning Car Co. (UK) Lockheed Martin (USA) Mack Trucks (USA) Modec (UK) Miles Electric Vehicles (USA) Myers Motors, LLC (USA) NovaBus (Canada) OshKosh Defense (USA) Paccar Inc/Peterbuilt (USA) Phoenix Motorcars (Canada) Smith Electric Vehicles (UK)

[a] Chris Morrison, *30 electric cars companies ready to take over the road*, Green.venturebeat.com, 10 January 2008.

[b] Biofuelsdigest.com, *The 50 Hottest Companies in Bioenergy*, December 2008.

POET (USA) Primafuel Solutions, Inc. (USA) Propel (USA) Origin Oil, Inc. (USA) Osage Bioenergy (USA) Qteros (USA) Range Fuels (USA) Raven Biofuels (USA) RECO Biodiesel (USA) Revnova Biofuels (USA)	Vert Biodiesel (USA) Virent Energy Systems, Inc. (USA) Vital Renewable Energy (Brazil) Walsh Bio Fuels, LLC (USA) Western Petroleum Co. (USA) Yokayo Biofuels, Inc. (USA) Zeachem, Inc. (USA)	Tata Motors (India) Tesla Motors (USA) Think (Norway) Toyota Motor Co. (Japan, USA) Velozzi (USA) Venturi (Monaco) Volvo Trucks (UK, Ireland, USA) Zap (USA)

Table F-3. Portable Power and Battery Company Listing[a],[b]

	Portable Power & Batteries	
Portable Power: Acumentrics (USA) Alternative Energy Resources (Canada) Ball Aerospace & Technologies (USA) Clean Fuel Systems, Inc. (USA) Connexa Energy, LLC (USA) Ecotech Intera Corp. (Canada) Energen Corp. (USA) Fuel Cell Technologies (Canada) Gillette Generators, LLC (USA) Horizon Fuel Cell Technologies, LTD (Singapore) Hydrogen Fuel Cell Motorsport (UK) Hydrogenics (Canada) Millennium Power Systems (India) Mobile Power Int'l (USA) MTI Micro Fuel Cells, Inc. (USA) P21 GmbH (Germany) Plug Power (USA) Power Innovations Int'l (USA) Powerplus Generators (Canada) Protonex Technology Corp. (USA) Redhawk Energy Systems, LLC (USA) Renewable Energy Systems (USA) Renewable Resources, LLC (USA) Sunworld Solar Energy Tech (China) Titan Power Systems (USA) Zap (USA) Zayas Energy (USA)	Batteries: A123 Systems, Inc. (USA) ADC Battery (China) Batech Korea, Inc. (South Korea) Battery Power Technologies (UK) Battery Specialties (USA) Battery Zone, Inc. (USA) Bindal & Bindal Batteries (India) BYD Battery Co., LTD (China) Candeo Solutions (Malaysia) China Origin Co., LTD (China) CSB Batteries (Netherlands) Daily Power Batteries (China) Duracell (USA) Dyno Battery, Inc. (USA) Eagle-Picher Technologies (USA) Energizer Holdings, Inc. (USA) Evergy Battery Corp. (USA) Evertek Battery (China) Exide Technologies (USA) Firstpower Technologies Co., LTD (China) GBT German Battery Trading GmbH (Germany) Genus Power Infrastructures, LTD (India) Goldman Technology Co., LTD (China) GP Batteries Intl (Singapore) Hitachi Maxell, Inc. (Japan) Hi-Energy Battery (China) High Power Tech Co. (China) Ion Energy (UK) Johnson Controls Battery, Inc. (USA) JSC (Russia)	Magnacharge Battery Corp. (Canada) M&D Technology Development Corp. (USA) Microcom Technologies (USA) Moltech Corp. (USA) NEC Tokin Corp. (Japan) NICA Power Battery Corp. (Canada) OnPower Technology, Inc. (USA) Panasonic (USA) Preferred Power Technologies (USA) PowerCell Batteries (UK) Renata Batteries (Switzerland) Sansa Power Source Co., LTD (China) Sanyo Energy Corp. (USA) Sharp Industries (India) Shenzhen Elite Electronic Co., LTD (China) Sinda Electronics Co., LTD (China) Suncom Battery Enterprises, LTD (Hong Kong) Suzhou Industrial Park East Battery (China) Swiss Batteries (Switzerland) Unipower (USA) Uniross Batteries GmbH (Germany) XenoEnergy Co., LTD (South Korea) Yuasa, Inc. (USA)

[a] Posharp.com, *Renewable Energy Business Database*, 2009.

[b] http://www.fuelcellmarkets.com.

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Appendix G

GLOSSARY

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AC	alternating current
AFDC	Advanced Vehicles Data Center (DOE)
AFV	alternative fuel vehicle
ARRA	American Recovery and Rehabilitation Act
AT&L	Acquisition, Technology, and Logistics
BAA	Broad Agency Announcement
BTL	biomas to liquids
Btu	British thermal unit
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CAPE	Cost Assessment and Program Evaluation
CARS	Cash Allowance Rebate System
CNA	Center for Naval Analyses
CNG	compressed natural gas
CONOPS	concept of operations
CRS	Congressional Research Service
CSIS	Center for Strategic and International Studies
CTC	Critical to Cost
CTL	coal to liquids
CTQ	Critical to Quality
CTS	Critical to Safety
DARPA	Defense Advanced Research Projects Agency
DCMA	Defense Contract Management Agency
DDR&E	Director Defense Research & Engineering
DESC	Defense Energy Support Center

DMAIC	Define, Measure, Analyze, Integrate, and Control
DoD	Department of Defense
DOE	Department of Energy
DSB	Defense Science Board
DSO	Defense Sciences Office (DARPA)
DT&E	Development, Test & Evaluation
EIA	Energy Information Administration
EISA	Energy Independence and Security Act of 2007
EMR	Evaluation Metrics Requirements
EPAct	Energy Policy Act
EUL	Enhanced Use Lease
FBC	fully burdened cost
FBCA	fully burdened cost of adoption
FBCF	fully burdened cost of fuel
FCS	Future Combat System
FED	Fuel Efficient Ground Vehicle Demonstrator
FoV	Family of Vehicles
FT	Fischer-Tropsch
GGE	gasoline gallon equivalent
GTL	gas to liquids
HEMT	Hierarchical Evaluation metrics Tree
HEV	hybrid electric vehicle
HMMWV	High Mobility Multi-Wheeled Vehicle
HOQ	House of Quality
HRDR	hydrogenation-derived renewable diesel
HTS	high temperature superconductor
IEM	Integrated Evaluation Method
IMO	International Maritime Organization
JCIDS	Joint Capabilities Integration and Development System

JLTV	Joint Light Tactical Vehicle
JUON	Joint Urgent Need
KPP	Key Performance Parameter
KSA	Key System Attributes
Li	lithium
LNG	liquefied natural gas
LOC	line of communications
LPG	liquefied petroleum gas
MISER	Mobile Integrated Sustainable Energy Recovery
MPG	miles per gallon
MRAP	Mine Resistant Ambush Protected
MTBF	mean time between failure
MTI	Mechanical Technology, Inc.
MW	megawatt
NAVAIR	Naval Air Systems Command
NiCd	nickel cadmium
NiMH	nickel metal hydride (battery)
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NRL	Naval Research Laboratory
O&S	operations and service
ONR	Office of Naval Research
PHEV	plug-in hybrid electric vehicle
PV	photovoltaic
QFD	Quality Function Deployment
R&D	research and development
RDECOM	Research, Development and Engineering Command (U.S. Army)

RDT&E	research, development, testing, and evaluation
REN21	Renewable Energy Policy Network for the 21st Century
RF	radio frequency
SKA	skills, knowledge, and ability
SLA	sealed lead acid (battery)
STO	Strategic Technology Office (DARPA)
TARDEC	Tank Automotive Research, Development and Engineering Center (U.S. Army)
TMA	Technology Maturity Assessment
TMAW	Technology Maturity Assessment Wheel
TRL	technology readiness level
UAS	unmanned aerial system
USD	U.S. dollars
V&V	verification and validation
VOC	Voice of the Customer

Appendix H

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14. ABSTRACT

This IDA report presents a wide-ranging view of existing and emerging alternative energy, fuel, and technology (renewable energy) sources for fixed infrastructure, vehicles (air, ground, maritime), and portable power systems. Additionally, this report describes the Technology Maturity Assessment Wheel (TMAW), Hierarchical Evaluation Metrics Tree (HEMT), and the Integrated Evaluation Method (IEM) that enable the *quantitative* comparison and evaluation of these renewable energy sources for DoD military systems, logistics, and operations applications. Development of the TMAW, HEMT, and IEM was accomplished using well-known market and product requirements tools such as the Quality Function Deployment (QFD) House-of-Quality (HOQ), Six Sigma Define, Measure, Analyze, Integrate, and Control (DMAIC) and Voice-of-the-Customer (VOC) techniques, Critical-to-Quality (CTQ) trees, and Critical-to-Safety/Critical-to-Cost (CTS/CTC) analysis. Key System Attributes (KSAs) and Key Performance Parameters (KPPs) are also described. A case study using the proposed integrated metrics-based evaluation method is presented for the Joint Light Tactical Vehicle (JLTV). Finally, a broad view of the renewable energy market (current and future investment) and existing companies is described.

15. SUBJECT TERMS

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